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June 10-11, 1982

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Subject: Proceedings of Western Mined-Land Rehabilitation Research Workshop

The enclosed proceedings of the Western Mined-land Rehabilitation Research Workshop held in Fort Collins, Colorado During June 1982 should be useful to resource managers and technical field personnel working in the area of energy and mineral resources.

The proceedings include current research, state-of-the-art application of current technology, future research needs and technology transfer processes for mined-land rehabilitation. Future research needs for mined-land rehabilitation are highlighted on pages 87 through 94.

Robert H. Arndorfer

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Western Regional Coordination Committee (WRCC-21), Reclamation of land displaced by coal, oil shale, and other mining activities.

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EXECUTIVE SUMMARY

A crucial ecological concern today is the disturbance of multiple use lands with energy and mineral resource extractions. In the past, reclamation of mine spoils was thought nearly impossible. But scientific research and the application of research results, since the early 1970's, has resulted in successful revegetation on sites once thought hopeless.

However, much still needs to be done, especially for lands with special requirements such as arid, alpine, acid, and sodic sites. Leaders in the field of western mined-land rehabilitation have recently focused on the most pressing of research needs and technology transfer needs. Their assessments are outlined in this report and are directed toward government and industrial scientists and land managers.

This report is the result of a June 1982 Western Mined-Land Rehabilitation Research Workshop held in Fort Collins, Colorado. Specialists reviewed rehabilitation progress to date, and recommended specific directions for further research and application.

CONTENTS

Page

Research Program Papers

Research on Rehabilitation of Mined Lands at Intermountain Forest and Range Experiment Station 1

Highlights of Mined-Land Rehabilitation Research Rocky Mountain Station 4

The Role of SCS Plant Materials Centers in Western Mined-Land Rehabilitation 8

Western Mined Land Reclamation 16

Land Reclamation Program: Argonne National Laboratory 21

The USDA-EPA Economic Impacts of Coal Development on Natural Resources Project 24

The Oil Shale Industry - Rehabilitation of Disposal Sites and Disturbed Areas 27

Mined Land Rehabilitation Research at Colorado State University 31

Breeding Superior Plants for Disturbed Lands 36

Research Conducted by North Dakota State University on the Reclamation of Strip-Mined Land 40

Water Harvesting on Surface Mine Spoils 45

Reclamation Research Through the Wyoming Agricultural Experiment Station, University of Wyoming: Current Status and Future Needs 49

Reclamation Research on Coal Mine Spoils by New Mexico State University 53

Identification of Technology Gaps and Research Needs for Western Mined-Land Rehabilitation Research by Forest Service Western Regions 56

Mined Land Reclamation in the Powder River Basin - Perspective of a Wildlife Biologist 58

Colorado State University Agronomy Department Disturbed Lands Research 61

Coal Hydrology Program of the U.S. Geological Survey 81

Page

Western Mined-Land Rehabilitation Research Workshop:
Research Needs 87

Specific Research Needs 87

I. Reclamation Planning 87

II. Spoil Placement and Grading 88

III. Soil Preparation and Treatment 89

IV. Spoil-Soil-Plant Interactions 90

V. Planting and Plant Materials 91

VI. Hydrology and Air 92

VII. Wildlife and Fishery Habitats 93

VIII. Postreclamation Management 94

Technology Transfer Needs 95

Appendix 97

List of Participants 98

Meeting Agenda 102

RESEARCH ON REHABILITATION OF MINED LANDS
AT INTERMOUNTAIN
FOREST AND RANGE EXPERIMENT STATION[1]

R. Duane Lloyd[2]

INTRODUCTION

The Forest Service research program is operated through eight regional Experiment Stations and a Forest Products Laboratory. The Intermountain Forest and Range Experiment Station is one of the eight, with a primary territory of Nevada, Utah, Idaho, Montana, and western Wyoming.

Forest Service research is authorized by the Forest and Rangeland Renewable Resources Research Act of 1978 and the Forest and Rangeland Renewable Resources Planning Act of 1974. The overall mission is to provide new knowledge, technology, and survey information for the management, utilization, and protection of renewable natural resources on public and private lands.

MISSION

This Station's research program includes work on the following objectives:

I. Develop methods and techniques for rehabilitating lands disturbed by mining in the interior West, particularly the Intermountain and Northern Rocky Mountain regions.

  A. Devise technology to establish and maintain protective vegetal cover on mine spoils.

    1. Identify plant materials adaptable to mine spoil environments.

    2. Develop methods for site preparation, seeding, and planting on mine spoils.

  B. Develop criteria for modification of mine spoil environments to enhance revegetation success, improve soil stability, and limit surface runoff.

II. Develop, test, and evaluate alternative surface mine planning and rehabilitation practices to economically achieve management and environmental goals.

10-YEAR ACCOMPLISHMENT SUMMARY

Research to achieve objective I has been conducted in a wide variety of locations and environmental conditions, and is related to several mineral commodities. These include:

Northern Plains	- shortgrass prairie	- coal
Intermountain area	- sagebrush-grass, pinyon-juniper, and salt desert shrub	coal and spent oil shale
Intermountain area	- Aspen-fir & sagebrush-grass	- phosphate
Northern Rockies	Lodgepole pine	- cobalt and copper
Northern and central Rockies	- Alpine tundra	- heavy metals
Sierra Nevada	- Mixed conifer	- sulfur
Great Basin	- Sagebrush-grass	- barite
Intermountain	- Sagebrush-grass	- uranium

Some studies involved fresh disturbance; others involved areas that had lain idle and barren for many years.

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[1] Report presented at the Western Mined-Land Rehabilitation Research Workshop, Fort Collins, Colo., June 10-11, 1982.

[2] R. Duane Lloyd, Assistant Station Director for Research, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Early in the program we identified the critical factors limiting rehabilitation and focused research attention on them:

- Erosion potentials of overburden and spoil.
- Mass slumping of overburden and spoil.
- Dark color and high surface temperatures of some spoil.
- Low availability of N,P, and K.
- Acidity of some areas due to oxidation of sulfides.
- Alkalinity of some sites.
- Heavy metal toxicities.
- Low water-holding capacities of overburden.
- Low moisture availability of sites in semiarid zones.
- Low moisture availability in high-cold areas.
- Short growing seasons in high-cold areas.
- Low availability of micronutrients.
- Lack of seed or plants of adapted species.

Most of the studies were applied research. We have been successful in developing and demonstrating ways of stabilizing and vegetating mined lands in all of the several combinations of environments and mine commodities. Our work has established some key guides to siting and shaping spoil dumps and banks; surface treatments; use of soil over spoil; use of fertilizers, mulches, and amendments; and use of adapted grasses, forbs, and shrubs.

Some fairly basic work has been conducted on soil-plant-water relations and selection of superior varieties of native plants.

Work on objective II also has been mostly applied research and has been conducted mostly in coal areas in the Northern Plains. Results include: Guidelines for construction and maintenance of mine haul roads to minimize dust and erosion; costs of reclamation of alluvial valleys and prime agricultural lands; and SEAMPLAN computer-based system for premine design and planning to provide for cost:effective rehabilitation.

Our scientists have reported their findings in over 65 publications plus many more informal papers, talks, etc.

We have had many cooperators including several universities, the Bureau of Land Management, National Forest personnel, the Environmental Protection Agency, and the Office of Surface Mining.

We have emphasized getting our findings into use. Many of our research results are used by mining companies, managers of public resources, and regulatory agencies.

Recently, we completed a handbook for Region IV, Office of Surface Mining that provides sound scientific and statistical procedures for people who inspect mine rehabilitation projects.

This Station was part of the SEAM (Surface Environment and Mining) Program. SEAM was a short-term (1973-1979) program designed to link industry, resource managers, and research, and to accelerate the development and application of technology for planning and executing mined land rehabilitation. Most of the SEAM effort involved this Station and the neighboring Rocky Mountain Forest and Range Experiment Station. SEAM produced a series of "user guide" publications.

CURRENT RESEARCH

Our current program is a continuation of the lines of work toward the major objectives outlined above. There has been some shift in emphasis. We are revising our objectives and reshaping the research with a new 5-year program.

Current work is following up on the longer-term effects and results of the rehabilitation work of some years ago. While site manipulation requirements, rates of application of seed and fertilizer, and specific cultural practices have been mostly resolved for mesic sites, more work is needed on the cold-wet and hot-dry environments. Continuing studies include plant succession, adaptive plant trials, concurrent revegetation with grasses, forbs, and shrubs, and alternative dump orientation and configurations to enhance microenvironments for optimum establishment and growth of plants. More emphasis is being given to the hydrologic characteristics and behavior of mine dumps. One new study is designed to examine the plant succession process on a series of oil and gas drill sites of various ages in Wyoming.

TECHNOLOGY GAPS

Intensive discussions with our own scientists, industry representatives, resource managers, and the academic community have led to identification of the following areas of "technology gap," "research needs," or research opportunities:

Conference topic area	Problem or technology need
1. Reclamation planning	• None

Conference topic area	Problem or technology need
2. Spoils placement and grading	• Information is needed to evaluate mining waste embankment design, construction method, groundwater occurrence, surface water drainage, and seismic events as they influence embankment mass stability.
3. Mine spoil preparation and treatment	• There is a need to modify and apply the Universal Soil Loss Equation (USLE) to mined lands for the design of erosion control systems and the prevention of sedimentation of aquatic habitats.
	• There is insufficient information to allow comprehensive evaluations, and subsequent control measures for mitigating acidic or saline spoils that adversely affect water quality.
4. Planting, and planting materials	• We need to identify additional plant materials adapted to potentially phytotoxic mine spoils or to mine spoils in arid environments.
	• We lack sufficient information about the establishment and maintenance of protective vegetal cover on mine spoils with potentially phytotoxic conditions or on mine spoils in arid environments.
	• Additional work to refine prescriptions for revegetation work.
5. Hydrology	• Adequate information is needed to evaluate the hydrologic characteristics of mining waste embankments and their effect upon streamflow regimes, embankment groundwater accumulation, and embankment water budgets.
	• We lack sufficient information to evaluate spatial and temporal variation of hydrologic and soil parameters of mined lands.
5. Hydrology cont'd	• We know very little about contamination or interruption of groundwater aquifers due to mining.
6. Wildlife and Fishery habitat	• Not enough is known about wildlife use of reclaimed mined areas nor how to design reclamation to meet the needs of wildlife and site stability.
	• Little is known about effects of exploration, drilling, and mining effects on wildlife.
7. Post-reclamation site	There is a need to evaluate plant community and population dynamics, including plant succession, diversity, and plant-animal interactions as they affect the long-term productivity of reclaimed mined lands.
	• Investigation is needed to evaluate alternate rehabilitation treatments on mine spoils as they influence long-term soil development and productivity.
8. Other	• Economics and institution issues need additional investigation, including: - Costs of reclamation - Downstream impacts - Historic and social issues of abandoned mines - Comparison of state reclamation laws - Permitting requirements - Severance taxes
	• We lack methods of rehabilitating high walls in the West.
	. Chemistry of acid mine drainage in the Northern Rocky Mountains is not fully understood.

HIGHLIGHTS OF MINED-LAND REHABILITATION RESEARCH

ROCKY MOUNTAIN STATION[1]

R. G. Krebill[2]

INTRODUCTION

The Rocky Mountain Station is one of eight regional experiment stations operated by the Forest Service. Our territory includes North and South Dakota, Nebraska, Kansas, Arizona, New Mexico, most of Colorado, the eastern two-thirds of Wyoming, and those portions of Texas and Oklahoma west of the 100th Meridian. The mission of the Station is to acquire the knowledge, develop the technology, and disseminate the research findings required to manage the area's forest and rangeland resources. Of the Station's eight laboratory locations, research directly related to surface mining has been a significant part of continuing programs at Albuquerque, Rapid City, Laramie, and Fort Collins. Research at Albuquerque is designed to develop methods to establish and maintain productive vegetative cover on southwestern coal and uranium mine spoils. At Rapid City, research focuses on techniques to establish stable ecosystems on mine spoils and associated water impoundments in the Northern Plains. Research at Laramie is concerned with determining potential impacts and ways to mitigate mining problems for elk and pronghorns in Wyoming. Research at Fort Collins involves modeling dispersion of air pollutants from surface mines and related energy developments.

REHABILITATION OF SOUTHWESTERN MINE SPOILS

In 1972, research at the Rocky Mountain Station laboratory in Albuquerque, New Mexico was redirected from rangeland watershed studies to research specific to rehabilitation of mine spoils in the Southwest. Research of the Albuquerque unit has led to the following major findings.

1. Natural recovery of mined lands in the Southwest is very slow (Wagner, Martin, and Aldon, 1978). After 13 years, study areas were still in early primary succession, mostly by introduced annuals such as Salsola kali and Hordeum jubatum. Native species that were found colonizing spoils and therefore of interest to rehabilitation programs include Chrysothamnus nauseosus, C. greenei, Sitanion hystrix, Atriplex canescens, A. saccaria, A. powellii, A. rosea, and Agropyron smithii.

2. Surface shaping, grading, and overlaying mine spoils with top soils can help to reduce wind and water erosion and conserve soil moisture for vegetation (Scholl and Aldon, 1979). Undulating topography left with a rather roughened surface of either productive top soil or spoils specially conditioned for plant growth, greatly increase chances for successful revegetation.

3. Soil microbiology appears to be an important aspect to establishing stable vegetative cover on mine spoils. "Top soils" obtained by mining alluvial washes may be deficient in beneficial organasims such as mycorrhizal fungi, which have been demonstrated to be of major benefit to Atriplex canescens, Chrysothamnus nauseosus, and several species of grasses (Aldon and Green, 1980). Other organisms such as soil termites have been shown to have potential for adding nitrogen to deficient soils (Ettershank, Elkins, Santos, Whitford, and Aldon, 1978).

4. Successful plantings on southwestern mine spoils can be made with relatively good expectations with Sporobolus airoides, Agropyron smithii, Chrysothamnus nauseosus, Hilaria jamesii, Kochia prostrata, Atriplex canescens, Distichilis stricta, Elymus junceus, and Secale montanum (Aldon, 1981; Aldon and Pase, 1981; Aldon, Scholl, and Pase, 1980). Other species which proved more erratic but nevertheless promising include: Agropyron desertorum, A. trachycarilum, A. sibiricum, Sporobolus cryptandrus, Melilotus officinalis, Elaeagnus angustifolia, Caragana arborescens, Kochia prostrata, Forestiera neomexicana, and Pinus edulis (Aldon, 1978).

5. Irrigation is required during the first season to assure plant establishment in areas with less than 8 inches of annual precipitation. Overhead sprinkling and drip irrigation have both proved successful (Aldon, 1978).

6. Mulching is usually necessary to overcome problems related to soil moisture, salt, and soil erosion which are common on southwestern mine sites. Straw, at rates of 3,000 lbs./acre, incorporated into the upper few inches of top soil has proven to be especially useful (Aldon, 1978).

---

[1] Paper presented at the interagency "Western Mined-Land Rehabilitation Workshop," Fort Collins, CO, June 10-11, 1982.

[2] Assistant Director for Research, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Forestry Sciences Laboratory, in cooperation with Arizona State University, Tempe, AZ

REHABILITATION OF MINE SPOILS IN THE NORTHERN PLAINS

Part of the research program of the Rocky Mountain Station's laboratory in Rapid City began concentrating on surface mine problems in 1975. The focus of this effort has been aimed toward revegetating mine spoils and impoundments to enhance habitat for nongame birds, deer, small mammals, and waterfowl. Major findings are:

1. Impoundments of water and drainageways on rangeland mine spoils can offer favorable habitat for wildlife (Hawkes, 1979; Olson, 1980, Olson and Baker, 1979).

2. To optimize wildlife values, slopes of impoundments should be graded so that shorelines are gradually sloping rather than steep (Hawkes, 1979b).

3. Top soils set aside during mining and later used to cover mine spoil surfaces help to both revegetate and reduce the amount of toxic minerals leached into mineland impoundments (Hawkes, Anderson, and Rumble, 1982).

4. Shrubs and trees can be successfully established on coal and bentonite spoils by selecting good planting stock and following good management practices (Bjugstad, 1979; Bjugstad, Yamamoto, and Uresk, 1981; Orr, 1977). Some of the most successful surviving species include *Fraxinus pennsylvanica*, *Shepherdia argentea*, and *Prunus americana* when irrigating bare root planting stock. *Pinus ponderosa* survival is significantly higher with the use of irrigation and container planting stock. *Caragana arborescens* has excellent survival with no irrigation and bare root planting stock. Direct seeding of forbs resulted in successful stands of most perennial native forbs tested on coal mine spoils (Bjugstad and Whitman, 1982).

5. Average small mammal densities were higher on reclaimed recently spoiled areas than on unmined sagebrush-grasslands (Hull, 1981). A similar situation occurred with invertebrate populations and not directly related with canopy coverage. *Peromyscus maniculatus* is the most abundant rodent in the sagebrush-grassland habitat type (MacCracken, Uresk, and Henson, 1982) and readily invades spoiled areas making this species a pioneering species. The rapid invasion by numerous rodents assists in accelerated dispersion of plant seeds.

6. Small mammals inhabiting uranium mine tailings recorded exposure levels of 1.3 milliroentgens per day on one uranium mill tailings covered with 30 cm. of top soil and 3.3 mR per day on another tailing covered with 30 cm. of top soil but with a higher background radiation count (Rumble, 1982). Small mammals on adjacent grasslands recorded exposure levels of 0.5 mR per day. Radionuclide content of plants on mill tailings covered with 30 cm. of top soil averaged 1.31 µg/g natural uranium, 0.18 pCi/g Thorium 230, and 11.3 pCi/g lead while the radionuclide content of plants on mill tailings covered with 60 cm. of top soil averaged 0.67 µg/g natural uranium, 0.74 pCi/g Thorium 230, and 5.35 pCi/g lead 210. Additional determinations are being conducted on the plant material to analyze difference between plant species.

MITIGATING MINING PROBLEMS FOR ELK AND PRONGHORNS

Much of the surface mining activity anticipated for Wyoming occurs in areas frequented, in at least part of the year, by elk, deer, or pronghorn antelope. To help set the stage for mitigation, the Laramie Lab is involved in cooperative studies concerning elk and pronghorn distribution and movement patterns in representative areas of south central Wyoming where surface mining is anticipated.

The elk study, located in the Little Snake River drainage is in its second year of a 5-year study. Most of the elk summer at higher elevations on National Forests, but winter in the potenital mining vicinity. About 120 elk are year-long residents of the Atlantic Rim, Miller Hill, and Buck Springs Draw areas. When movement patterns are better determined, it should be possible to map the sensitive areas where activity should be avoided.

The pronghorn study was begun in 1979 through Dr. Irwin at the University of Wyoming and much has been learned about movement and habitat requirements in the Red Rim/China Butte area. Through radio telemetry and visual observations, it is becoming apparent that pronghorns of the area tend to prefer the areas of high topographic relief during winters, apparently because of the potential to find shelter from wind and snow-free slopes, plateaus, and ridges for browsing. They also require water and tend toward greater use of areas near water holes, especially during the drier times of the year.

Other studies at the Laramie Lab were aimed at providing ecological criteria for evaluating mine restoration projects and on methods for rehabilitation of mine spoils in alpine areas. John Thilenius has a draft manuscript on ecological criteria in process and the research results on the alpine area were not encouraging enough to continue the study.

AIR QUALITY IN RELATION TO SURFACE MINING AND ENERGY DEVELOPMENT

The Rocky Mountain Station Meteorology/Air Quality Research Unit in Fort Collins, in cooperation with the Bureau of Land Management and Colorado State University, has been studying the emission of fugitive dust resulting from coal mining activity near Craig, Colorado, since 1979. Both coal and overburden dusts are plentiful, especially during dry, windy periods (Dietrich, Marlatt, and Fox, 1980). Particle emissions are generated from a complex array of sources--the mine pit, coal storage piles, coal handling facilities, and especially haul roads are significant. Patterns of trace material showed that haul roads were responsible for the vast majority of the particles.

Approximately 35 percent (weight) of the particulates collected in hi-vol samplers exceeded 7μm and about 35 percent were smaller than 1μm. In general, particulates were smaller than expected and of concern as they are more likely to be dispersed over long distances to contribute to problems of visibility. In order to help evaluate the potential effects of surface mine generated pollutants on visibility, a monitoring site has been operating since 1979 near Craig. Measurements using a contrast telephotometer and a nephelometer confirm a background visual range of 150 km or greater (Dietrich, et al., 1980). Plans to measure the chemical constituents of the ambient air are to be implemented this summer.

To predict transport and dispersion of pollutants from mines, recent research of the unit has been aimed at improving the air quality model TAPAS (Topographic Air Pollution System) (Fox and Fosberg, 1970, Childs and Marlatt, 1981). TAPAS combines a model for air movement over complex terrain (WINDS), with various procedures to calculate pollutant dispersion and the potential for stagnation in airsheds along with regulatory criteria. TAPAS has been run in northwestern Colorado in order to illustrate its potential use for coal leasing activities (Wood, Fox, and Marlatt, 1981). Recently TAPAS has been upgraded by the inclusion of a new modeling technique (CITPUFF) to calculate dispersion of pollutants in mountainous topography. This new version of TAPAS will soon be evaluated by BLM for its usefulness in predicting environmental impacts related to pollution from major developments such as oil shale. A priority in the future is to introduce a deposition mode into TAPAS so that acidic deposition both wet and dry can also be predicted.

THE FUTURE FOR SURFACE MINE RESEARCH BY THE ROCKY MOUNTAIN STATION

Long range Forest Service planning under the umbrella of the Renewable Resources Planning Act (RPA) calls for a substantial increase in research by the Rocky Mountain Station to address problems related to energy development in the Rocky Mountains and Southwest. If fully funded, this program would strengthen existing research, and add a major effort to address both on-site and off-site effects of mining activities associated with oil, gas, and oil shale exploration in the central Rocky Mountains.

In the near term, the Rocky Mountain Station is sharing the research budget reductions, but through 1983 we expect only a slight reduction of in-house capability to address surface mine research problems. Consequently, our cooperative research efforts on surface mine problems will remain among the strongest of all our cooperative ventures.

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THE ROLE OF SCS PLANT MATERIALS CENTERS IN WESTERN MINED-LAND REHABILITATION

Jack R. Carlson [1]

The USDA Soil Conservation Service operates a network of 23 plant materials centers (PMC's) nationwide to assemble, screen, select, increase, field test, and release plants for commercial production and use in soil conservation programs. Plant materials centers work in close cooperation with soil conservation districts, state agricultural experiment stations, state agencies, other federal agencies such as the U.S. Forest Service and Bureau of Land Management, and private groups to meet the need for conservation plants. The centers are guided by SCS program priorities, which currently emphasize work on severe erosion problems and watershed treatment to reduce flood damages.

Mined-land reclamation assistance is a routine activity of several SCS field (county) offices in the intermountain west. As a result, the need for adequate sources of improved conservation plants for minespoils is expressed in the long range programs for the Bridger (Montana), Bismarck (North Dakota), Aberdeen (Idaho), Tucson (Arizona), Meeker (Colorado), and Los Lunas (New Mexico) PMC's. This need is rated medium to high priority at all centers and has been emphasized since the early seventies. PMC testing on mined-land reclamation problems has been assisted with funding provided by SEAM, Office of Surface Mining (OSM), EPA, and private mining companies. Assistance from federal sources is continuing and private and state sources are increasing. Future direct PMC involvement with minespoil testing will depend largely on these outside funding sources, although current priority work on rangeland watershed improvement will provide plant releases that can be used on mined land. Similarly, work on minespoils provides information useful in meeting range improvement objectives.

The SCS plant materials program is integrated into ongoing conservation programs carried out in Soil Conservation Districts. PMC's conduct initial evaluations of large numbers of plant accessions, increase promising lines, make controlled plot evaluations at problem area sites, and establish large scale fields of final selections. On the other hand, SCS field offices collect most of the native accessions, work with district cooperators to establish field-sized plantings of promising selections, determine performance in actual field conditions, and provide assistance to seed growers or nurserymen that produce PMC releases. Each plant generally is released cooperatively with state agricultural experiment stations and other agencies that participate in its development. This process has resulted in 70 plant releases in the 13 western states. Of these about half have been tested on minespoils. Most are grasses.

Table 1 summarizes SCS plant releases with high value for minespoil revegetation and their commercial production in 1980.

As can be seen, most available plant materials are grasses and only recently have shrubs and forbs been released. Commercial seed is available for many native shrubs and forbs but supplies usually are collected in the wild, are sporadic, and vary in quality. There are obvious advantages to cultivated seed fields, seed orchards, field tested germplasm, and seed certification standards: proven adaptation, uniform high seed quality, higher seed yields, better establishment and performance, and more efficient job contracting.

Several new plants will be released by western PMC's in the next decade that will be recommended for use on mined-lands. All are in advanced stages of testing and included in Table 2.

Several of the projected releases are accessions selected and tested by the U.S. Forest Service Shrub Sciences Laboratory. In such cases, the PMC involved cooperates by producing seed for field-sized plantings with conservation district cooperators and when the plant is released the PMC seed field or orchard becomes the foundation source for commercial growers.

In addition to plants nearing release, numerous species are in less advanced stages of testing. Seventeen selections, including named cultivars, of fourwing saltbush are being compared by PMC's at 15 sites throughout the Western United States to determine how many cultivars are needed to obtain reasonable performance within the range of the species. A similar trial is underway for 8 selections of winterfat and 10 accessions of alkali sacaton. Other native species selections in plot testing on minespoils include Canada wildrye, Nevada bluegrass, sweet sage, thurbers fescue, plains bristlegrass, Arizona cottontop, Eaton penstemon, Rydberg penstemon, slender wheatgrass, arrowleaf balsomroot, cane bluestem, desert saltbush, and big galleta.

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[1] Plant Materials Specialist, USDA-Soil Conservation Service, West National Technical Center, Portland, Oregon 97209.

Table 1.--SCS plant releases with high value for minespoil revegetation and their commercial production in 1980.

Cultivar	Year Released	PMC	Production (lbs)
Arriba western wheatgrass (N)	1973	Los Lunas	77,000
A-68 Lehmann lovegrass	1950	Tucson	15,300
Bromar mountain brome (N)	1946	Pullman (Wash.)	4,000
Canbar canby bluegrass (N)	1979	Pullman	2,000
Covar sheep fescue	1977	Pullman	21,500
Critana thickspike wheatgrass (N)	1971	Bridger	278,000
Durar hard fescue	1949	Pullman	135,000
Ganada yellow bluestem	1979	Los Lunas	250
Goshen prairie sandreed (N)	1976	Bridger	10,530
Hachita blue grama (N)	1980	Los Lunas	480
Lovington blue grama (N)	1963	Los Lunas	10,200
Luna pubescent wheatgrass	1963	Los Lunas	270,000
Magnar basin wildrye (N)	1979	Aberdeen	14,400
Manchar smooth brome	1943	Pullman	404,493
Nezpar Indian ricegrass (N)	1978	Aberdeen	33,775
Nogal black grama (N)	1971	Los Lunas	280
Paloma Indian ricegrass (N)	1974	Los Lunas	35,300
Rosana western wheatgrass (N)	1972	Bridger	68,800
Redondo Arizona fescue (N)	1973	Los Lunas	8,750
Secar bluebunch wheatgrass (N)	1980	Pullman	--
Sodar streambank wheatgrass (N)	1954	Aberdeen	158,813
Tegmar intermediate wheatgrass	1968	Aberdeen	48,000
Vaughn sideoats grama (N)	1940	Los Lunas	16,200
Whitmar beardless wheatgrass (N)	1946	Pullman	52,160
Viva galleta (N)	1979	Los Lunas	1,650
Big Horn Skunkbush Sumac (N)	1979	Los Lunas	6,000 plants
Casa quailbush (N)	1979	Lockeford (Calif.)	2,500 plants
Jemez New Mexico olive (N)	1978	Los Lunas	9,000 plants
Marana fourwing saltbush (N)	1979	Lockeford	2,500 plants
Montane mountain mohogany (N)	1978	Los Lunas	6,000 plants
Wytana fourwing saltbush (N)	1976	Bridger	none
Bandera Rocky Mtn. Penstemon (N)	1973	Los Lunas	200
Appar lewis flax (N)	1980	Aberdeen *	--

*Cooperative release with USFS Shrub Sciences Laboratory.

(N) Native plants

Table 2.--New plants will be released by western PMC's for use on mined-lands.

Accessions	PMC	Projected Release Date
T2950 bluebunch wheatgrass (N)	Aberdeen	1/
PI109012 crested wheatgrass	USFS/Aberdeen	1982
PI109072 orchardgrass	USFS/Aberdeen	1982
T5356 basin wildyre (N)	Bridger	1/
T5424 Indian ricegrass (N)	Bridger	1/
T5294 nutall saltbush (N)	Bridger	mid 80's
T4644 littleleaf sumac (N)	Los Lunas	1983
T3553 fourwing saltbush (N)	Tucson	1/
T3885 Palmer penstemon (N)	USFS/Meeker	1983
T3602 oldman saltbush	Tucson	mid 80's
PI330671 quailbush	Tucson	mid 80's
T4495 sideoats grama (N)	Los Lunas	1982
NM1447 Indian ricegrass (N)	Los Lunas	1984
T7844 winterfat (N)	USFS/Los Lunas	1983
T4549 winterfat (N)	Los Lunas	1982
T4557 apacheplume (N)	Los Lunas	Late 80's
U103p fourwing saltbush (N)	USFS/Meeker	1982
PI314929 prostrate kochia	USFS/Aberdeen	1983
(Fountain Green) bitterbrush (N)	USFS/Meeker	1983
(Janesville) bitterbrush (N)	USFS/Los Lunas	1983
(Hobble Creek) Vasey big sagebrush (N)	USFS/Meeker	1985
(Elk Creek) mountain rye	USFS/Pullman	1984

1/ Pending comparison with standards in field plantings.

Large assemblies of several species are in initial testing at western PMC's which when selected and released, will be useful on minespoils. These include shadscale, scarlet globe mallow, mat muhly, mormon tea, Wright's buckwheat, range ratany, bush muhly, salina wildrye, spiny hopsage, squirreltail, needle and thread, tobosa, wolftail, giant sacaton, hawthorn, chokecherry, buffalo berry, and sand dropseed. Emphasis in both the initial and advanced testing stages is on native plants.

A survey of SCS range site descriptions in the intermountain west and desert areas shows 84 grass, 64 shrub, and 42 forb species (or complexes) occur in significant amounts, which would be considered for seeding deteriorated sites or disturbed sites for erosion control if cultivars were available. Table 3 shows progress in developing cultivars of these species.

Table 3.--Progress in development of cultivars.

Plant type		Total Species	Released Cultivars Species	Released Cultivars Number	Advanced Evaluation Species	Advanced Evaluation Accessions	Species in Initial Evaluation Planted	Species in Initial Evaluation Collected	Species with Limited or No Evaluation
Grass	No.	84	23	32	10	37	20	5	26
	%		27%		12%		24%	6%	31%
Shrub	No.	64	6	7	16	35	7	11	24
	%		9%		25%		11%	17%	38%
Forb	No.	42	2	2	9	12	6	3	22
	%		5%		22%		14%	7%	52%
Total	No.	190	31	41	35	84	33	19	71
	%		16%		19%		17%	10%	38%

Overall, only 31 species (16 percent) of the species have available cultivars. However, another 76 species (40 percent) are currently in various testing stages at PMC's, intended for release. The U.S. Forest Service Shrub Sciences Laboratory also has a major shrub and forb development program and recently has cooperated with PMC's on the release and foundation production of proven accessions. The efforts of both SCS and Forest Service programs are reflected in the above table. Native grass and legume breeding efforts are underway by ARS and agricultural experiment stations, but usually involve improvements upon cultivars of widespread major species, such as blue grama, Indian ricegrass, and alkali sacaton. Exceptions would be tufted hairgrass and Utah sweetvetch.

Many of the grasses that have not been tested have limited ranges, are relatively minor, or are very difficult to handle agronomically. Future emphasis will be on completing work underway with the 35 native grasses for which there are no cultivars. For shrubs and forbs, PMC's, the Shrub Science Laboratory, and ARS Crops Research Laboratory (working on native legumes) combined have a considerable future workload. Only nine shrub and forb cultivars have been released. The three agencies recently have coordinated their testing programs to permit cultivar releases sooner.

Although PMC's are concentrating on native species for revegetating minespoils, promising introduced accessions are evaluated on minespoils as well. Sources of improved introduced plants include the ARS Crops Research Laboratory, agricultural experiment station breeding efforts, and PMC selections from projects unreleated to minespoils.

Six western PMC's have field tested plant materials on minespoil sites for several years. These plants primarily evaluate selections from initial testing, selections from other sources, and the interaction of seedbed preparation, planting dates, mulching seeding method, soil amendments, irrigation, seed mixtures, and/or seeding rates to obtain desired plant composition and cover. Table 4 is a list of PMC replicated plot trials on minespoil sites.

Table 4.--PMC replicated plot trials on minespoil sites.

Location	Type Mine	PMC	Year Started	Type Evaluation
Simplot Gay Mine SE ID	Phosphate	Aberdeen	1977	Site preparation - 18 treatments
			1976	Fertilizer - 8 treatments
			1976	Alfalfa adaptation - 20 accessions
			1976	Grass adaptation - 36 accessions
			1976	Forb adaptation - 77 accessions
			1976	Indian ricegrass establishment - 10 treatments
Simplot Conda Mine SE ID	Phosphate	Aberdeen	1976	Forb adaptation - 78 accessions
Monsanto Henry Mine SE ID	Phosphate	Aberdeen	1976	Grass adaptation - 36 accessions
Monsanto Ballard Mine - SE ID	Phosphate	Aberdeen	1965	Grass and Forb adaptation
Hecla Mine Wallace, ID	Silver	Pullman	1981	Species adaptation - 32 accessions
Eagle Picher Mine Lovelock, NV	Diatomaceous Earth	Aberdeen	1976	Species adaptation - 43 accessions
Exxon Colony Project Rifle, CO	Oil Shale	Meeker	1973	Species adaptation - 36 acc x 2 sites. Add'l 5 accessions ea in 1976, 78, 80
Energy Fuels Steamboat Sprgs, CO	Coal	Meeker	1977	Species adaptation - 68 accessions
Colo-Wyo Mine Craig, CO	Coal	Meeker	1977	Species adaptation - 84 accessions
TOSCO Bonanza, UT	Oil Shale	Meeker	1977	Species adaptation - 143 accessions Rodent repellant study

Table 4.--PMC replicated plot trials on minespoil sites - continued.

Location	Type Mine	PMC	Year Started	Type Evaluation
AMAX Mine Climax, CO	Molybdemum	Meeker	1977	Species adaptation - 63 accessions
			1977	Species adaptation - 26 accessions
			1981	Species adaptation - 19 accessions
Standard Metals Silverton, CO	Hard Rock (Silver)	Meeker	1978	Species adaptation - 70 accessions
				Rodent repellant study
			1981	Large rock mulch x 6 species
Kerr Mine Walden, CO	Coal	Meeker	1980	Species adaptation - 34 accessions
				Mulch x snow fence x tillage - 7 treatments
H&G Mine Craig, CO	Coal	Meeker	1981	Species adaptation - 34 accessions x 3 aspects
Bridger Coal Rock Springs, WY	Coal	Bridger	1980	Species adaptation - 273 accessions dryland, 137 irrigated
Big Horn Ranch Buffalo, WY	Coal	Bridger	1976	Species adaptation - 73 accessions
			1977	Forage production - 28 accessions
Cordero Mine Gillette, WY	Coal	Bridger	1978	Species adaptation - 27 accessions
			1978	Forage production - 18 accessions
Dresser Minerals Greybull, WY	Bentonite	Bridger	1981	Species adaptation - 325 accessions x 3 planting dates
North American Coal Zap, ND	Coal	Bismarck	1975	Forage/wildlife - 30 accessions
			1976	Species x mulch - 129 treatments
Wilton Mine GMA Wilton, ND	Coal	Bismarck	1976	Site prep x mixture x mulch - 16 treatments
				Site prep x species - 120 treatments
N. Beulah Mine GMA Beulah, ND	Coal	Bismarck	1976	Site prep x mixture x mulch - 16 treatments
Baukol-Noonen Center, ND	Coal	Bismarck	1975	Species adaptation - 41 accessions
Kaiser Steel Raton, NM	Coal	Los Lunas	1979-80	Species adaptation - 27 accessions
			1979	Seeding meth. x mixture - 8 treatments
			1979	Mulch x seed mixture - 24 treatments
			1979	Weeping lovegrass - 15 accessions
			1979	Species x containers - 20 treatments
Molycorp Questa, NM	Molybdemum	Los Lunas	1980	Seed mix x mulch - 12 treatments
			1980	Species adaptation - 74 accessions
			1980-81	Seeding methods - 6 treatments
			1980	Mulches - 15 treatments
			1980	Topsoil x fert - 32 treatments
			1981	Mulches - 7 treatments
			1981	Species adaptation - 20 accessions
			1981	Seed mix & topsoil - 6 treatments
			1981	Seeding methods - 6 treatments
			1981	Species adaptation (tailings - 18 accessions

Table 4.--PMC replicated plot trials on minespoil sites - continued.

Location	Type Mine	PMC	Year Started	Type Evaluation
Sun Belt Da-Na-Zin Farmington, NM	Coal	Los Lunas	1981 1981	Species adaptation - 10 accessions Seeding rate x topsoil x seedbed prep x irrigation - 30 treatments
Utah International San Juan Mine Farmington, NM	Coal	Los Lunas	1981 1981 1981	Seeding meth. x rate x mixture - 24 treatments Mulch x seed mixture - 36 treatments Species x fert - 72 treatments
Cypress-Pima Mine Green Valley, AZ	Copper	Tucson	1978	Species adaptation - 8 accessions
Cities Service Mine Miami, AZ	Copper	Tucson	1978	Species x aspect - 14 treatments
Phelps-Dodge Morenci, AZ	Copper	Tucson	1978 1978	Species adaptation - 15 accessions Tailing modification - 15 treatments
Sacaton Mine Casa Grande, AZ	Copper	Tucson	1978	Species adaptation - 28 accessions
Kennecott Mine Hayden, AZ	Copper	Tucson	1978 1978	Species adaptation - 17 accessions Species x lime - 28 treatments
Phelps-Dodge Aho, AZ	Copper	Tucson	1978	Species adaptation - 23 accessions
ASARCO Silverbell, AZ	Copper	Tucson	1978	Mulch - 3 treatments
ASARCO Mission, AZ	Copper	Tucson	1978	Mulch - 3 treatments
ANAMAX Green Valley, AZ	Copper	Tucson	1982	Seedbed x species x mulch - 36 treatments

In general, adequate ground cover has been achieved in at least some plots at all sites except in extreme low precipitation zones (below 9 inches), harsh sites at high altitudes, and acid copper mine tailings. In northeast Wyoming, minespoil seedings have been as successful and productive as normal efforts on undisturbed range sites suitable for reseeding. As expected, topsoil capping over minespoil is an essential treatment for reestablishing vegetation. Results from most above studies have not been summarized, analyzed, or published yet, so other trends may become evident as this is done.

Finally, numerous minespoil field plantings have been made with conservation district cooperators--usually private mining companies. In the past 15 years, 59 plantings have been made at 43 sites. Table 5 lists field plantings established since 1968 (very few were installed prior to this time). Plantings have ranged from small row plantings to large scale seedings, and in almost all cases, are established and maintained by the cooperators. Performance data are recorded separately for each state and have yet to be consolidated into a regional summary report. However, some of the results were used to develop SCS TP-157, "Plant Materials for Use on Surface-mined Lands in Arid and Semi-Arid Regions," published in 1982.

Table 5.--Field plantings established since 1968.

Location	Type Mine	Year	Shrubs	Herbaceous
McDermitt Mine McDermitt, NV	Mercury	1978	X	X
Eagle Picher Mine Lovelock, NV	Diatomaceous Earth	1978		X
Plateau Mine Panguitch, UT	Uranium	1981	X	X
Kennecott Mine Salt Lake City, UT	Copper	1976		X
Tower Resources Price, UT	Coal	1980	X	X
New Jersey Zinc Eagle, CO	Zinc	1976	X	X
Anschutes Glenwood Springs, CO	Coal	1978	X	X
Union Carbide Craig, CO	Uranium	1980	X	X
Rio Blanco Oil Shale Meeker, CO	Oil Shale	1982	X	X
Gold Ore, Ltd. Cripple Creek, CO	Placer	1982		X
Ideal Cement Canon City, CO	Limestone	1978-80	X	X
Idarada Mine Norwood, CO	Hard Rock (Silver)	1977,80	X	X
Peabody Coal Norwood, CO	Coal	1979,80	X	X
Energy Fuels Steamboat Springs, CO	Coal	1977	X	X
Edna Mine Steamboat Springs, CO	Coal	1974,75	X	X
Union Carbine Rifle, CO	Uranium	1968		X
Phelps-Dodge Silver City, NM	Hard Rock (Silver)	1973	X	X
Earth Resources Cuba, NM	Copper	1976	X	X
Hepp Bros. Buffalo, WY	Coal	1975		X
Rocky Mtn. Energy Casper, WY	Uranium	1981		X
S. Barron Gillette, WY	Coal	1973	X	
AMAX Gillette, WY	Coal	1976		X
Atlantic Richfield Gillette, WY	Oil Well (drill pads)	1978		X
Kerr-McGee Gillette, WY	Coal	1979		X
Black Hills Bentonite Kaycee, WY	Bentonite	1971,75		X
Texas Gulf Cripple Creek, CO	Gold	1982		X
American Colloid Sundance, WY	Coal	1971		X
Kerr-McGee Douglas, WY	Uranium	1975		X
Pacific Power & Light Douglas, WY	Coal	1977		X
Exxon-Highland Douglas, WY	Uranium	1977		X
Utah International Medicine Bow, WY	Coal	1971		X
Guernsey Stoneworks Wheatland, WY	Stone quarry	1974		X

Table 5.--Field plantings established since 1968 - (continued).

Location	Type Mine	Year	Shrubs	Herbaceous
Dresser Minerals Greybull, WY	Bentonite	1973-74,80		X
Wyo-Ben Greybull, WY	Bentonite	1982		X
Kemmerer Coal Cokeville, WY	Coal	1975		X
Union Pacific Railroad Cokeville, WY	Coal	1968		X
Knife River Coal Sidney, MT	Coal	1971	X	X
Kalfell Coal Terry, MT	Coal	1972		X
Western Engergy Forsyth, MT	Coal	1974	X	X
Westmoreland Resources Hardin, MT	Coal	1974	X	X
Decker Coal Hardin, MT	Coal	1974,79-81	X	X
State of Montana Roundup, MT	Coal	1974		X
Anaconda Whitehall, MT	Copper	1981,82	X	X

Performance generally verifies the data accumulated on promising accessions in PMC controlled trials, although establishment success has been somewhat lower because of lower levels of management in a field setting. However, there are examples of outstanding planting successes, such as Decker Mine in Big Horn County, Montana, and Union Pacific Railroad in Lincoln County, Wyoming.

In summary, SCS has released 33 plant cultivars which are being used to revegetate minespoils in the West. Within 8 years another 22 accessions, mostly shrubs and forbs, are planned for release, many joint releases with the U.S. Forest Service. However, an additional 87 native species, important components of range and woodland plant communities, are in initial and advanced stages of testing, for which there are no cultivars. SCS plant materials centers will continue to test, select, and release improved lines of these remaining species, supported significantly by data from plot trials on minespoils and field plantings with mining company cooperators. The rate at which new plant releases occur will depend in part on continued federal (non-SCS), state, and private funding support of PMC operation.

WESTERN MINED LAND RECLAMATION

Western Energy and Land Use Team
Fort Collins, Colorado

Phillip L. Dittberner and Robert G. Streeter

The Fish and Wildlife Service role in reclamation is to provide information and recommendations to industry and other resource managers, to insure adequate protection for fish and wildlife resources. Past and ongoing studies are described, and technology gaps listed.

A. The Western Energy and Land Use Team (WELUT) Program in Western Mined-Land Reclamation

The Fish and Wildlife Service, as an agency within the U.S. Department of Interior, does not have mineral management responsibilities. However, together with its sister agencies, the Bureau of Land Management and the Geological Survey, the Fish and Wildlife Service does have the responsibility to assist the Department in its accelerated coal development program and other mineral management planning. As such, the Fish and Wildlife Service has been assigned the advocate role for the fish and wildlife resources of the nation to assure that the fish and wildlife resources of the United States are given adequate consideration in the decision-making process. The Fish and Wildlife Service accomplishes this by providing the best available quantitative information possible for use at the various levels of decision-making processes related to energy development. Under its legislative and executive mandates, the Fish and Wildlife Service received funding and manpower resources to establish the Office of Biological Services and a field component, the Western Energy and Land Use Team located in Fort Collins, Colorado. This team is composed of a variety of talents including traditional fish and wildlife biologists, political scientists, remote sensing specialists, systems analysts, and information transfer specialists. This interdisciplinary group plans and directs projects related to obtaining, analyzing, and transferring the best available information so that it is presented to the proper decision-making level in a proper form and in a timely manner as a useful tool in the development of proper consideration of fish and wildlife resources in the final decision trade-offs.

The goals of the Western Energy and Land Use Team, relative to surface mining, are to consider the requirements of the fish and wildlife resources of the nation and:

1. Identify geographic areas unsuitable for mining and associated activities;
2. Establish a preferred sequence and pattern of mining and associated developments for areas the FWS considers suitable for mining; and
3. Develop and test strategies to minimize impacts and maximize benefits of energy development on fish and wildlife resources.
    - a - Provide summaries of stipulations for protecting fish and wildlife resources in concert with FWS and State field personnel and BLM, OSM, and USGS.
    - b - Develop guidelines for applying state-of-the-art methodologies toward reclaiming for fish and wildlife goals jointly with FWS, BLM, USFS, and State field personnel.
    - c - Develop interagency, demonstration/pilot projects to apply and test state-of-the-art reclamation methodologies for fish and wildlife habitats, develop strategies and updated guidelines for operational implementation jointly with FWS, BLM, USFS, OSM, USGS and State field personnel and industry.
    - d - Develop and conduct various training and educational activities to enhance the effective consideration of fish and wildlife resources in reclamation plans by industry and regulatory agencies.

B. Past WELUT Projects in Western Mined Land Reclamation

1. Rehabilitation of Western Wildlife Habitat: A Review.

The objectives of this project were to provide a review and perspective of information available from previous research about habitat requirements of key wildlife species and to review the major land rehabilitation techniques that have been shown to be successful in research projects and are being used in rehabilitation and reclamation projects.

Information is presented, along with general synecological and autoecological information about plant species to be considered in a systems planning format for rehabilitation of wildlife habitat. The systems planning format is designed to stimulate thinking and increase the validity of considerations during the total rehabilitation planning process for wildlife habitat and wildlife values.

The rehabilitation planning process includes predisturbance inventory, identifying goals or objectives, preparing the plan, implementing the plan, post-rehabilitation management, and follow-up assessment. This manuscript concentrates on providing the information needed to make rehabilitation planning more effective in identifying goals for rehabilitation of wildlife habitat and developing the rehabilitation plan to increase the effectiveness and successfulness in rehabilitating wildlife habitats.

Subject areas where additional research is needed are identified and ways to better integrate habitat research and rehabilitation technology are suggested. The areas needing additional research were identified by the authors and the interdisciplinary workshop participants.

2. The Plant Information Network (PIN).

PIN is a computer-based data bank for rapidly storing, organizing, and retrieving information on the native and naturalized vascular plants of several western States. The system currently has information on over 5,000 plants found in Colorado, Montana, North Dakota, Utah, and Wyoming.

PIN is an expansion and modification of an earlier plant information system called "RAPIC" (Rapid Access Plant Information Center), developed by Dr. Robert Adams at Colorado State University (CSU). The RAPIC system was created to make biological and herbarium information on native Colorado plants more accessible to land managers, botanists, and other interested persons.

The PIN data bank evolved from the need for additional baseline data on plants to aid in the planning and mitigation of resource development in the West. Both the geographic coverage and information content of the system was expanded.

The basic information units of the PIN data bank are called "descriptors" and "descriptor states." Each descriptor corresponds to a plant attribute entered in the system. Descriptors are divided into mutually exclusive categories or descriptor states, which represent the possible ratings a plant may be given for a descriptor. For example, *good*, *fair*, *poor*, and *unknown* are the descriptor states for the descriptor, ENERGY VALUE.

PIN currently lists information on over 500 descriptors, under the general headings of taxonomic, geographic, biologic, ecologic, and economic plant attributes.

Each descriptor and descriptor state has a specific definition. Effective querying of the system and proper interpretation of information received from PIN requires an understanding of the descriptor and descriptor state definitions.

Descriptors and descriptor states can be used in any combination to obtain the specific information that is desired from the data bank. For example, by using the following descriptors and descriptor states, a list of grasses occurring above 11,000 feet in Larimer County, Colorado can be obtained: FAMILY, *Poaceae* and MAXIMUM ELEVATION-CO, greater than 11,000 and LARIMER-CO, present or reported. Any descriptor information of interest can be printed for these plants, such as their life cycle or habitat.

There are many potential uses for data in the PIN system. Information commonly requested from PIN and its major applications include:

(1) Relatively site-specific plant lists to aid in conducting vegetation inventories, ecological research, and other field studies.

(2) Ecologic attributes and economic values of plants to assist in the preparation of land management plans and environmental impact assessments.

(3) Information describing the adaptability and desirability of plants for revegetation of disturbed lands to aid in formulating or reviewing reclamation plans.

(4) Distribution and habitat data on rare and endangered plants to help verify their presence or absence.

The solving of problems, such as those encountered in land use planning, environmental impact assessment, protection of culturally important plants, and rehabilitation of severely disturbed lands, is certainly more complex than the ability to obtain and organize information. Nonetheless, the convenient and cost-effective retrieval of pertinent data is an important aspect of confronting these problems. For this reason, the development of the PIN system is a positive step toward improving the understanding, management, conservation, and stewardship of western ecosystems.

For further information about PIN and its use, please contact the Western Energy and Land Use Team at the address below.

Plant Information Network
USDI Fish and Wildlife Service
Western Energy and Land Use Team
Drake Creekside One, 2625 Redwing Road
Fort Collins, Colorado 80526
Commercial Telephone: (303)226-9389 or
(303)226-9388; FTS: 323-5389 or 323-5388

3. Practices for Protecting and Enhancing Fish and Wildlife on Coal Surface Mined Land.

This project reviews information on the "Practices" to protect and enhance fish and wildlife resources on surface mined land in five regions of the United States. These are Central and Southern Appalachia, South-Central U.S., Powder River-Fort Union, Green River-Ham's Fork, and Uinta-Southwestern Utah Regions. Current state and federal legislation was reviewed to determine those practices which were most compatible with the performance standards related to Best Technology Currently Available, Fish and Wildlife Plans, and Reclamation Plans. The risks and limitations, the approximate cost, and the maintenance and management requirements of each practice. Reclamation plans are also included, which integrate the practices with the restoration of specific habitats in the region.

These handbooks are presented as a "first approximation" of design specifications, to document effective field techniques being used, and to highlight sources of information for techniques that are now in use. This review also considers equipment, devices, systems, and methods that have proven useful in special cases.

The handbooks have been arranged to first present a section on the planning needs for fish and wildlife resources during the mining process. Regional problems are identified and the specific needs that individual sites might have are highlighted. Planning needs which are discussed include gathering baseline data, the evaluation of site potential, goal-setting, the preparation of a fish and wildlife plan and reclamation planning.

Next, practices for protection and enhancement of fish and wildlife resources are presented. The format for each practice generally follows the topical outline below:

Purpose: The usefulness of each practice is explained, giving its geographic and habitat applicability.

Development: The steps for implementing each practice are given, emphasizing its relationship to postmining land uses and compatibility with other practices.

Maintenance and Management: Considerations of the long-term upkeep requirements of some practices are identified.

Labor and Materials: To give some idea of the cost of implementing a practice, levels of effort are given in terms of man-hours, types of personnel, and dollar values (where costs could be estimated). Equipment and construction materials are itemized where applicable.

Sources of Information: For further assist- the following information has been provided where it was available: the company or agency who used or proposed the practice, government contacts, and useful literature such as books, journal articles, technical publications and studies.

Finally, reclamation alternatives are given for specific habitats in the region. For a typcial site within a habitat, appropriate practices are presented which are compatible with the terrain and indigenous fish and wildlife resources. These reclamation alternatives are designed to be used as an example of what could be done for fish and wildlife under a certain set of environmental conditions in the region. As a guide, they can offer ideas and suggestions to aid an operator with the preparation of a site-specific reclamation plan.

4. Impact of Strip-Mine Reclamation Practices: A Simulation Study.

The goal of this project was to develop a simulation model which would replicate, in a reasonable fashion, the response of a strip-mined site to a variety of reclamation procedures and environmental perturbations. Despite the facts that (1) the model does not include all components of the ecosystem, (2) some processes need to be better represented within the model, (3) many more data are required before the model can be validated, and (4) in its current state, the model is predictive only in a qualitative sense (i.e., output information should be evaluated in terms of relative magnitudes of change rather than focusing on absolute values). Despite these shortcomings, the model does in fact respond in a reasonable way to the reclamation procedures simulated here. The output responses generally agree with the results obtained in reclamation field studies and are similar to the responses anticipated in reclamation guidelines (Cook et al. 1974).

It seems that the model responds realistically because the mechanisms and processes represented in the model apparently replicate reasonably what actually happens in reclamation procedures. So in addition to replicating results obtained in reclamation field studies, analysis of model output suggest why and how the observed responses occurred.

In its present state, the model can be used to conduct experiments on possible effects of some reclamation treatments for sites in the Colstrip area. Because the model has not been validated, results of such experiments can only be considered as qualitatively applicable; nevertheless, such experiments can be conducted much more rapidly through simulation than by actual field studies. Therefore, the model may be used to supplement (but not replace) reclamation field studies in the Colstrip area.

Possibly the most valuable aspect of the simulation model lies in its integrative capacity. Using the model, we can evaluate the effects of a single treatment (such as fertilization) or multiple treatments (fertilization, irrigation, and topsoiling) on single output variables (plant biomass) or multiple output variables (net primary production and secondary production), simultaneously. This integrative capacity suggests the interactions among various treatments (such as topsoiling and fertilization) and demonstrates how one treatment can be used to replace or complement another and why one treatment must sometimes be applied in order to receive benefit from a second treatment.

This simulation model must be considered preliminary in the sense that more work can be done to improve it and many more field data are needed to facilitate model improvement.

5. A Northern Pike Spawning and Rearing Marsh Using Effluent Water From a Surface Coal Mine.

A demonstration project to rear fish in mine discharge water for use in stocking the sport fishery of the Tongue River Reservoir was conducted from 1977-1980 in southeastern Montana with Decker Coal Company; the U.S. Fish and Wildlife Service; Montana Department of Fish, Wildlife and Parks; and the Montana Cooperative Fishery Research Unit cooperating. The Decker Mine typifies surface coal mining in the Northern Great Plains and results from this study should be widely applicable to similar mines, operational or planned, in Wyoming, North and South Dakota and Montana.

There were two primary objectives for conducting this study. The first was to enhance the sport fishery for northern pike (Esox lucius) in the Tongue River Reservoir. The second objective of the study was to demonstrate that wastewater from a surface coal mine was of sufficient quality to allow survival and growth of northern pike. Ancillary components of the study included the construction of waterfowl nesting islands in the marsh for use by resident ducks and Canada geese and an evaluation of furbearer use of the newly developed marsh habitat.

The major findings of this demonstration project indicated that wastewater in the sedimentation pond was of sufficient quality to support the aquatic life. Northern pike eggs were fertilized, water-hardened and hatched in effluent water from the Decker Coal mine with no observed adverse effects. A 50-60 percent hatch resulted, which compares favorably with standard hatchery operations with northern pike, and fish growth was good for the five months of the experiment. There was also an indication mine discharge water used to fill the pike marsh provides a potential for improved water quality after storage in the marsh, particularly in regards to sodium, iron, sulfate and conductivity.

Pike fry were stocked in the marsh in 1978 and 1979; the 1979 production exeeded production figures reported for most pike marshes elsewhere in the United States. Use of the marsh for spawning habitat proved not to be a cost effective technique when compared to fry stocking.

A likely contribution of marsh produced pike to the sport fishery of the Tongue River Reservoir is indicated by an increase in estimated numbers of pike harvested; 57 pike for 1975 as compared to 110 pike for 1981. Catch rates also increased from 0.009 to 0.014 from 1975 to 1981, respectively.

Recommendations are presented in the project final report for future projects of a similar nature.

C. Current WELUT Projects in Western Mined Land Reclamation

1. Practices for Protecting and Enhancing Fish and Wildlife on Coal Surface Mined Land - Beluga Area of Alaska.

This project is very similar to the project described above (No. 3) as a past WELUT project. The major differences are the geographic area the handbook will be prepared for (Beluga Coal Field of Alaska) and this handbook will emphasize practices to be used to protect and enhance habitat for anadromous fishes and related environmental variables (i.e., surface and subsurface hydrology).

2. Ecology of Selected Plant Species for Revegetation in the West.

The objective of this project is to synthesize literature which is currently available on the ecology of selected plant species and present it in the form of a handbook with a consistent format. This will provide the reclamation specialist, resource manager, rancher, and other interested individuals with the information they need to select those plant species which are adapted to the site, compatible with each other, and will obtain the intended land use following mining, development, or management activities.

Since this handbook will contain information on each species' site adaptability, the information is pertinent not only to drastically disturbed lands, such as coal mines and oil shale development, but also to other minor disturbances, such as pipelines, oil well developments, and reseeding cropland, back to some vascular plant community.

Project tasks shall include:

(1) Conducting a thorough literature search for each species to be included in the handbook.

(2) Obscure or rare species which are not normally available from a commercial plant material supplier, will not be included. The handbook will concentrate on those species that are considered dominant, subdominant, or major component species for the major western United States plant communities that occur in Arizona, Colorado, Montana, Nevada, New Mexico, North Dakota, Oklahoma, Texas, Utah, and Wyoming.

(3) Each species included will have a description of approximately two to four pages, with a detailed line drawing plus distribution maps.

3. Evaluation of Best Management Practices (BMP) for Mine Solid Waste Disposal and Treatment.

The Western Energy and Land Use Team, in cooperation with the Environmental Protection Agency, will evaluate in depth the adequacy of various management techniques being used by the mining industry for the treatement, storage, and disposal of mining waste under Section 1008 or 3004 of RCRA. Three industry segments have been selected for this study based on the volume of solid waste produced and their potential for causing air and water problems. Those selected segments are phosphate mining (including slimes), uranium mining (excluding tailings), and metallic ore mining, such as copper, iron, lead, molybdenum, silver, gold, and zinc.

A preliminary study has been conducted which surveys specific existing waste management practices of these industry segments. The preliminary study will supply a listing of the best management practices in use for mine waste rock, overburden, low grade ore, tailings, milling waste and sludges from treatment and processing plants. The listing will include a discussion of the practices, their limitations (i.e., site, climate, or type mine), and an estimated cost of the technique.

The variables monitored will include the water quality (surface and ground water) and air quality at mining sites to evaluate the effectiveness of specific practice(s) utilized in solid waste management to protect the environment. In addition, the practices will be evaluated and their limitations determined (e.g., site, climate, or type of mine), and the cost of the practices will be estimated.

Based on the results of the preliminary study and recommendations, a minimum of ten (10) and maximum of twenty (20) practices will be selected for detailed evaluation and monitoring. One or more practices may be located at a single mine site. These sites will represent varied geological, topographical, climatic, etc. regions of the country.

D. Technology Gaps

1. Reclamation Planning, Legal/Institutional Constraints.

- ° Characterization of the site to be rehabilitated with reference to its quality and potential.
- ° Vegetation mosaic definition, utilization, microclimate, physical sites, soil configuration, diversity, and stability of wildlife habitat.
- ° Evaluation of impacts of Federal, State, and local policies and regulations as they affect the rehabilitation of mined lands.
- ° Clarification of purpose: legal constraints, coordination, integration of biological (plant and animal), social demands, and goals for reclamation.
- ° Development of methods and techniques for rehabilitation of disturbed sites.

2. Planting and Planting Materials.

- ° Selection of plant species in suitable balance; techniques of establishment.
- ° Plant selection: propagation sources of native shrubs and forbs.
- ° Development of particular techniques needed to revegetate for wildlife.
- ° Development of better plant materials for wildlife habitat rehabilitation. Included in this would be plant materials sources and their production, autecology of desirable species, and methods for their establishment.

3. Wildlife and Fishery Habitat.

- ° Better definition of habitat characteristics and physical-biological features that animals prefer.
- ° Achievement of diversity of plants and animal communities. Definitions of habitats and their use by animals.
- ° Biology of game and nongame species, their habitat requirements and behavior as related to plant species structure and design of the community.
- ° Development of combinations of reclamation techniques to provide diverse habitats. This includes vegetation arrangements, species, spacing, etc. and topographic manipulation to give slope aspect, ponding, etc.
- ° Determination of impacts of environmental alterations due to mining rehabilitation and associated activities on wildlife.

4. Post-Reclamation Site Management.

- ° Evaluation of plant and animal species change following rehabilitation.
- ° Investigation of successional patterns in both plants and animals after project development. This includes monitoring animal responses, population changes, and migration patterns in relation to plant community changes.
- ° Determination of successional trends and efficient techniques for monitoring these trends using indicator species.

LAND RECLAMATION PROGRAM

ARGONNE NATIONAL LABORATORY

Sponsored by Department of Energy

RALPH P. CARTER, PROGRAM MANAGER

MISSION

Coal will continue to be one of our most attractive energy sources for the foreseeable future. Unlike petroleum, coal is abundant within the borders of the United States. Although serious concern exists about our ability to mine and burn coal in an environmentally acceptable manner, there is confidence that many of these problems can be solved through the use of appropriate research and development. Since 1973, it has been clear that our national security and the continued growth of our industrial society depends on sensible utilization of our domestic energy resources. There is also increasing evidence that the export of coal holds great potential for helping to restore the U.S. balance of trade. It is entirely possible that during the next four years and beyond, numerous changes will be made to government regulations, including the environmental controls associated with coal mining. Regardless of these developments, there is general agreement that coal mining must be done in a responsible manner that protects our national resources for the generations that follow.

The new administration will play a strong role in future coal production and it is possible that towards the end of this century, coal production will exceed the current high predictions. A considerable emphasis will be placed on making energy resources available for mining and on simplifying certain environmental regulations. Because coal makes up about 80% of our national energy, there is general agreement that coal must play a stronger role in our energy supply for the next 20 to 50 years.

The fact remains, however, that surface coal mining extracts a heavy toll on the soil, biological systems, and hydrological systems of the disturbed landscape. To date, and estimated 0.93 x 10^6 ha (1 hectare = 2.471 acres), of the United States have been disturbed by coal mining. It is also estimated that more than 4 million ha of land in the conterminous United States are underlain by strippable coal reserves. Information contained in this list suggests that surface mining will or has occurred in 28 states, 6 of which could have a disturbance greater than 2 x 10^5 ha. Clearly, there exists a need for comprehensive long-term high-risk research in order to solve current and future environmental problems associated with this disturbance.

In 1975, the Land Reclamation Program was initiated at Argonne National Laboratory to investigate alternative reclamation approaches that could be used in ameliorating the adverse impacts of surface mining. When the United States Department of Energy (DOE) was established in 1977, it assigned to its Office of Health and Environmental Research the task of developing new reclamation methods to prevent or reduce damages caused by surface mining. However, before that task can be accomplished, more must be learned about the functioning of organisms and their surroundings, that is, the ecosystems threatened by disruptions from surface mining. While new federal and state laws require the full reclamation of mine sites, there is no assurance at present that reclaimed areas can be self-sustaining in the long term, especially in the arid and semiarid West, or that the scarce water supplies in the West will not be adversely affected by surface mining.

The Land Reclamation program is designed to solve the wide range of problems associated with the surface mining of coal. Basic and applied studies seek energy-efficient and cost-effective methods to reclaim land and ways to pass on that information to government, industry, and the environmental community. LRP research is aimed at understanding more clearly soils, plants, animals, hydrologic systems, and other ecosystem components in order that ways may be found to improve environmental quality and prevent damage from mining. The research ranges from such broadly based studies as determining the effects of mining on the hydrologic balance to very specific studies such as an evaluation of the reproductive cycle of a native grass with potential as a revegetation species. Another aim of the program is to produce efficient and cost-effective techniques for returning to productive use land that has been disturbed by mining. Such research supports the DOE Reclamation Research Plan, which focuses on the maintenance of environmental quality while meeting energy production goals.

ACCOMPLISHMENTS

- Developed proof, at the Jim Bridger Mine in western Wyoming, that areas with unstored topsoil applied directly over graded overburden have developed a stand of volunteer native shrubs and grasses 500% greater than that of a similar area covered with two-year-old stored topsoil. Vegetation cover on the unstored topsoil plot is almost equal to that on unmined areas after only four years. Based on these results, the Bridger Coal Company has begun a mine-wide reclamation practice of direct reapplication of topsoil whenever possible in order to improve revegetation success. The research results also suggest that, by the use of direct topsoil reapplication methods developed by the LRP, operators will probably be able to meet the OSM-mandated ten-year revegetation success responsibility period for arid sites.

- Developed, through plant breeding and selection research, six "super-plants" that are specifically adapted for mine reclamation in the arid West. These hybrid shrubs have survived the dry, saline/clay environment on mined land in the Four Corner area of New Mexico better than any native plants. This was achieved at a mine that the recent INFORM study (Reclaiming the West) has concluded should not have opened because it probably could not be reclaimed. The production of hybrid seed at near-commercial quantities is now underway for these plants.

- Determined, through studies to quantify environmental impacts of surface mining on hydrologic systems in the West, that no appreciable adverse changes have occurred because of the mining operation at the Big Horn Mine on the Tongue River, and that irrigated farming probably has a more adverse effect than does the mine.

- At the Macoupin County, Illinois, coal refuse reclamation demonstration project, research data indicate a significant improvement in environmental quality and a substantial increase in the economic value of the site and adjacent property. The Consolidation Coal Company has used information from this project in its refuse reclamation effort at Piney Fork, Ohio, coal preparation plant. In Missouri, the Department of Natural Resources is using the project's design data for its refuse reclamation plans submitted by coal operators.

- The LRP is conducting mine-scale prime farmland reclamation studies at the Consolidation Coal Company's Burning Star Mine #3 in southwestern Illinois. Research emphasis is on evaluation of alternative minesoil construction and agricultural management techniques for returning mined land to acceptable levels of row crop production. Greenhouse experiments show no significant differences in plant yield when comparing blended and segregated subsurface minesoil materials. This suggests that the choice of subsoil materials should be based on cost when soils are reconstructed during reclammation of some prime farmland areas. Economic data from this site demonstrates the very high -- and perhaps unnecessary -- costs of constructing a minesoil from segregated soil materials during reclamation of prime farmland.

CURRENT MINED-LAND RECLAMATION RESEARCH

JIM BRIDGER MINE PROJECT

Research by the Land Reclamation Program at the Jim Bridger Mine is designed to provide insight into the problems associated with the successful and permanent reclamation of surface-mined land in an arid environment. Successful reclamation implies the cost-effective establishment of a vigorous ecosystem that has all the functional components of the premining ecosystem and that is appropriate to the area and the final land use. The Bridger site, located in the Red Desert region of southwest Wyoming, receives only 7.5 to 30 cm of precipitation per year (average 15 cm/yr), about half of this as snow. The extreme variability of precipitation from year to year makes this a harsh site even for the native biota.

Research during the past four years has emphasized measurements of vegetative cover, phenology, production, and below ground ecosystem development on mined land resulting from several different topsoil handling techniques (stored topsoil replacement vs. direct topsoil reapplication, without storage) and methods to improve the capture and retention of soil moisture -- essential for plant establishment -- by snow fences and various surface manipulations. Basic studies of the complex role of microorganisms, such as mycorrhiza, in the ecology of arid soils is also being investigated through a series of field and laboratory experiments. These experiments are designed to provide insight into the complete reestablishment of functioning ecosystems, rather than merely the cosmetic revegetation of mine spoils. Documenting wildlife recolonization, the use of reclaimed areas by wildlife, and the grazing impacts of herbivores is also an important part of this multidisciplinary project.

The ongoing research at the Jim Bridger Mine, while providing much data, answers to critical questions, and the bases for recommendations, has also generated many new reclamation questions that cannot be adequately answered using the existing research site. One such question involves the entire process of topsoil segregation, storage, and reapplication that is required by federal and state laws on land mined for coal. Data and observations from this site indicate that direct-applied topsoil, four years after reapplication to graded overburden, has developed plant cover with a native species component five times greater than a similar area covered with topsoil that had been stockpiled for two years prior to reapplication. Immediate topsoil reapplication, although desirable, may not always be possible or economical at an operating surface mine. In these cases, how long can topsoil be stockpiled before it loses the advantages inherent in freshly applied, unstored material? What happens to the seeds and other viable propagules that are present in fresh topsoil? What are the physical and biological bases of the marked differences that have been observed and quantified? What new, cost-effective mining and reclamation engineering practices can be developed and tested to directly apply fresh topsoil? What are the effects of alternative topsoil replacement techniques on soil structure (e.g., compaction).

Another area of concern at arid reclamation sites such as Jim Bridger Mine is the availability of adequate moisture for the germination and successful establishment of revegetation plant species. Supplemental irrigation is but one approach, and has not yet been proven successful or cost-effective in the long-term. What are the true long-term total costs of large-scale reclamation using supplemental irrigation? Can direct application of fresh topsoil or the use of snowfences be considered as alternatives to irrigation, based on the success and economics of the resulting permanent vegetative cover? What are the impacts of small grazing mammals on the relatively lush "green islands" of irrigated reclamation sites? Assuming adequate moisture is available to revegetation plants, will sufficient levels of plant nutrients be available to produce a vigorous stand? What is the role of the soil microbiological community in nutrient cycling?

NAVAJO MINE PROJECT

In order to develop plant species or varieties that are well adapted for revegetation of minesoils at the Navajo Mine, the Jim Bridger Mine, and other western mine sites, a selection and breeding project has been developed by Dr. Howard Stutz at Brigham Young University (BYU). This project uses all major evolutionary strategies: mutation, hybridization, autopolyploidy, and allopolyploidy. Experimental work is being carried out at field plots at the Navajo Mine, the Bridger Mine, and in nursery, greenhouse, and laboratory studies at BYU in Provo, Utah. Because even the undisturbed soils at both the Navajo and Bridger experimental sites are harsh environments for the plants that occupy them, studies aimed at the successful revegetation of these sites have emphasized research on plants that appear to be preadapted to such conditions. The plants used in this research are members of the family Chenopodiaceae and grasses from the tribe Hordeae. Because of its extensive genetic variation, ease of hybridization, propensity for polyploidization, and demonstrated capacity for tolerating saline soils and drought, the genus Atriplex (saltbush, shadscale) had been given the most attention.

TECHNOLOGY GAPS

The recently completed National Academy of Science study entitled Surface Mining: Soil, Coal, and Society[1] states that: "The development of appropriate reclamation policies and practices in the diverse environments of the several coal regions in the United States depends upon adequate technical information and an efficient and effective institutional setting in which to make choices. Long-term studies should be made of the full impacts of alternative reclamation approaches. Research is needed to characterize mine sites; on the weathering of mine spoils; on the movement of soluble nutrients, particularly in the high-rainfall areas of the South and East; on the hydrologic properties of the mined areas; on the appropriateness of grading to original or other contours; on means of avoiding or dealing with compaction of the root zone; on methods of controlling soil erosion; on appropriate vegetation regimes in the reclamation process; on the most cost effective reclamation methods to reestablish diverse self-sustaining ecosystems in the arid and semiwest, including new reclamation tools such as plants and innovative mining methods to reestablish native vegetation without supplemental irrigation; on the reintroduction of biological populations, nutrient cycles, and organic matter formation in new soil; on the appropriate level of productivity to which land would be returned and the time required to do so; and on the appropriate procedures for dealing with special problem areas."

LITERATURE CITED

[1] National Academy of Science Report, Surface Mining: Soil, Coal and Society; 1981, 233 p., Washington, D.C.

THE USDA-EPA ECONOMIC IMPACTS OF COAL DEVELOPMENT ON NATURAL RESOURCES PROJECT[1]

John W. Green[2]

Abstract.--This joint EPA-USDA Project has collected data describing the coal network from resources to utilization points. A transportation model and an interregional competition model have been developed to integrate the data and perform policy anaysis. One of the features of the system is its ability to accurately predict the location and amount of mining activity and, therefore, the requirements for reclamation. Amounts of solid wastes from coal preparation plants and power plants can also be accurately predicted.

The USDA-EPA Economic Impacts of Coal Development on Natural Resources Project is a joint effort between the USDA's Economic Research Service (Natural Resource Economics Division) and EPA's Office of Research and Development. The Project was initiated in 1975 and continues to be funded to assess impacts on rural communities and natural resources resulting from existing and proposed energy, environmental, and agricultural policy options.

The Project has collected and merged data bases describing the coal network (resources, flow patterns, firms, and institutions). These data bases contain information on coal resources, characteristics, mining, preparation, transportation and utilization. The data bases are constantly being expanded and updated to make them more complete, comprehensive, and timely. A data base management system has been developed to integrate the bases and the models used to analyze alternative policy scenarios. The Project relies heavily on historical data to perform accurate short-run analyses on which to base longer run investigations.

The numerous data files can be divided into four components describing the coal network; each component contains too much information to be put into a single, formal Data Base Management System (DBMS). As a result, seven logical DBMS structures are currently used to organize the data. The DBMS structure used is the Scientific Information Retreival (SIR) package designed to accompany the SPSS analytical package and is fully implemented on the CDC computers at Colorado State University (CSU).

The four similar data components consist of production-supply, transportation-distribution, utilization-demand, and location-geographic (fig. 1). Each of these components is discussed below. Refer to figure 1 for lists of data bases in each group.

The production-supply data define, as completely as possible with publicly available data, the coal resource, production, and preparation portion of the coal network. The USGS National Coal Resources Data System (NCRDS) is constantly being updated and new versions of the base are periodically obtained by the Project. The NCRDS can be supplemented by state and private data, depending on the application. The NCRDS, along with the washability file, has been used to statistically evaluate distributions of mined coal characteristics and to evaluate the characteristics of remaining reserves. We are ready, when funding becomes available, to evaluate the availability of those reserves. The federal lease data can be used for a wide variety of applications relevant to the assessment of supply-demand balances and the need for additional federal leasing. The three alternative mine data bases are routinely compared to assess reporting differences, to create a more comprehensive inventory of mines, and to perform production and productivity analyses. The labor union affiliation base was obtained for use in assessing risks and impacts of supply disruptions caused by UMW strikes. The coal preparation plant inventory was developed by the Project at the request of EPA. It is hoped that the inventory can be updated and other information verified during FY-83.

The transportation-distribution data exist in two locations. Data at North Dakota State University (NDSU) is used to support a Transportation Analysis System (TAS) developed

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[1] Paper made available at the Western Mined-Land Rehabilitation Workship, Fort Collins, Colorado, June 10-11, 1982.

[2] John W. Green is Regional Economist, Natural Resources Economics Division, Economic Research Service, U.S. Department of Agriculture, Colorado State University, Fort Collins, Colorado.

PRODUCTION-SUPPLY	
USGS	National Coal Resources Data System (NCRDS)
BLM	Federal Leases
BOM	Washability
MSHA	Mines
OSM	Mines
EIA	Form 7 Bituminous Coal and Lignite Production
EIA	Coal System Section of Energy Data Bank
MSHA	Labor Union Affiliation
USDA	Coal Preparation
TRANSPORTATION-DISTRIBUTION	
EIA	Form 6 Distribution of Coal
NDSU	Transportation Analysis System (TAS)
MARAD	Docks and Ports
ICC	Rail Network
TVA	Deliveries to TVA Plants
EIA	Form 423 Utility Fuel Deliveries
UTILIZATION-DEMAND	
EIA	Form 3 Manufacturing Coal Consumption
EIA	Form 5A Coke and Coal-Chemicals
EIA	Generator Unit Reference File (GURF)
EIA	Utility Company Information File (CIF)
EIA	Utility Joint Ownership File (JOF)
USDA	Power Plant Master File
EIA	Form 4 Power Plant Fuel Use
USDA	Coal Contracts
EPA	Power Plant SIPS
FERC	Form 67 Plant Air and Water Quality Control Data
EPA	National Emissions Data System (NEDS)
EPA	Sulfate Regional Emissions Inventory (SURE)
URGE	Power Plant Unit Inventory File
LOCATION-GEOGRAPHIC	
NBS	Federal Information Processing Standards (FIPS)
CENSUS	Master Community Coordinate File (MCCF)
CENSUS	DIMECO
USGS	County Coordinates

Figure 1.--Coal network data components.

under contract to the Project. The NDSU maintains rail and waterway networks and other data describing the location of producing and consuming units, transportation transfer points, and state-county boundaries for data plotting purposes. Colorado State University maintains files describing all parts of the coal distribution network except the actual rail and water network and the TAS. Therefore, CSU analyzes the distribution and delivery of coal from producing counties to consuming plants, not the actual origin-destination movements.

The utilization-demand data contain publicly available data describing coal consuming points, the source and amount of coal used, the other resources required (land, water, etc.), and the outputs produced (electricity, air pollution, ash, etc.). Numerous analyses have been performed with these data to support the Interregional Coal Analysis Model and to answer other questions concerning coal consumption. This data is capable of answering a wide variety of questions concerning coal utilization and the physical operating characteristics of the plants.

The location-geographic data are used to standardize all location codes, addresses, and geographic identifiers attached to production, transportation, and utilization activities. In addition, NDSU has utilized computer plotting equipment to display information extracted from coal network data. Similar capabilities exist at CSU but are not as convenient to use.

The coal network data described above have been used to develop two analytical models, the Transportation Analysis System (TAS) at NDSU and the Interregional Coal Analysis Model (ICAM) at CSU. The TAS is a transportation network model which provides inputs for the ICAM, but which is also capable of independent, stand-alone transportation optimization. The ICAM is used primarily to simulate the existing or proposed coal network but is also capable of stratified optimization.

The Project contracted with Dr. Ken Ebeling in the Industrial Engineering Department at NDSU to build the TAS, which incorporates available rail and barge network data of the United States. The Model can load coal at any point on the network and move it to any destination on the network--keeping track of capacity over individual rail and barge links and developing an engineering cost for each movement. Alternative optimization routines can be used to influence the routing of annual coal shipments. Suboptimization is performed when several mine sources are allowed to compete for the supply of coal at a specific plant. The ICC's Uniform Rail Costing System is now being integrated into the engineering cost algorithms of the TAS.

The above data bases and methodology have been integrated using a modular linear programming framework formally described as the Interregional Coal Analysis Model (ICAM). Three modules have been developed: one describing coal mines and mining, the second describing the transportation network and its optimization output, and the third describing the coal-fired utility industry. Each of these modules is discussed in more detail below.

The mining module uses the county as its basic building block. The mine file describes mine sources of coal for each year, 1975 through 1981. A contracts file can be compared with the origin-destination delivery data. Data describing coal characteristics is monitored as input for determination of alternative sources of supply. Mine information and coal sources are aggregated to the county level before entry into the ICAM. Therefore, in the mining module, each county's coal reserves, characteristics, production, and other relevant information are monitored. Each year, as mines produce coal to supply power plants, the reserves in each county are reduced. Production accumulates and coal is transferred to the transportation module. Other relevant inputs describing the coal mining industry, such as water and land use coefficients, can be added to this module. The mining module can also be tied to a coal preparation module. Data for that module is being collected via an inventory of advanced coal cleaning plants, including an assessment of the level of cleaning occurring at each of these plants. In addition, engineering cost algorithms are being developed to evaluate total network costs when coal preparation options are being considered.

Another relevant analysis performed at CSU is an assessment of changes in the prices paid for coal by power plants. Historic data from 1973 through 1980 are analyzed, after a transportation cost has been backed out, to develop regional short-run models that forecast coal prices. A national short-run price model was developed and used to forecast prices to 1990. The selling prices serve as input to the mining module of the ICAM.

A second module in the ICAM describes the transportation of coal from its source to its destination. The coefficients in this module are provided by the TAS. This module accepts coal from the mining sector (or from the cleaning sector) and transports it to the power plant. A cost for the movement is obtained from the TAS. Capacity constraints for individual movements are used in this module to distribute coal according to historical patterns. Normally, only one transportation link is provided for each movement but scenarios can be analyzed which allow power plants to choose from alternative nonhistorical sources of supply. In such an application, the modular linear programming approach would more closely approximate traditional linear programming optimization analysis. Alternative transportation modes, such as coal slurry pipelines, can be added to this module or to the TAS operating as a stand-alone analytical model. Alternative decision-making objectives on the part of producers, carriers, and consumers can also be specified. These include maximizing initial carrier linehaul distance, minimizing linehaul costs or distance (default technique), maximizing mainline routing, or maximizing waterborne routes.

The third module describes the coal-fired utility industry. Each power plant using coal as a fuel, either wholly or in part, is described in the data supporting this module. Data are also maintained describing planned intentions for new energy facilities using coal as a fuel. For example, announced intentions for new coal-fired power plants are monitored and each new plant listed according to its owner, location, source of coal, and year in which it is scheduled to begin operation. Similar data files are maintained for new coal-fired industrial boilers, synthetic fuel plants, and power plant conversions.

Additional data have also been collected describing power plant consumptive water demand and effluent quantities, including pollutants. Extensive manipulation of EIA Form 67 data and other air and water quality data have been performed to make them useful in analyses describing historic plant operating characteristics. Econometric predictive equations have been developed to estimate the annual percentage of time which a power plant will operate, the heat rate for each plant in terms of Btu of coal inputted per kilowatt hour of output, water use for cooling and slag removal, and amounts of air pollution produced.

A demand model for predicting residential electricity use is also available. This demand model was developed to provide estimates of electricity demand to drive the linear programming model. However, the ICAM currently emphasizes short-run analysis and uses announced intentions for new capacity as an electricity supply constraint rather than estimating demand and using a demand constrained optimization approach. The residential electricity demand model was developed by Dr. John R. McKean at CSU and is a two-equation, econometric model describing the demand for residential electricity by utility service area. The first equation describes historical stocks of electric appliances in the residential sector; the second equation describes the rate of usage of this stock of electric appliances.

Areas which we would like to aggressively pursue include loading agricultural and freight commodities onto our rail and barge network to determine intercommodity competition impacts. We would like to computerize the highway network in one or two states and merge them with our rail and barge network to ascertain impacts and interconnections between mines and preparation plants, farm and country elevators or terminals, and accessibility of undeveloped Federal and private coal reserves. We could perform analyses of sulfur dioxide production to determine economic impacts on agriculture and forest production resulting from acid rain. Similarly, competition for land because of solid and liquid waste production treatment and disposal should be analyzed. We would like to refine our econometric demand analysis, perhaps applying it to specific rural and urban utility service areas. We would like to merge the oil and gas pipeline network into our transportation network to determine markets for synthetic fuel produced from coal and assess impacts on agricultural fuel distribution and use.

THE OIL SHALE INDUSTRY - REHABILITATION OF DISPOSAL SITES AND DISTURBED AREAS[1]

Joe. M. Merino[2]

Abstract.--Tosco Corporation has been involved in reclamation research for over 15 years. Laboratory determinations of spent shale chemical and physical characteristics, and both greenhouse and field study plots of various spent shale/soil treatments indicate high pH, soluble salt content and nutrient problems are solved through management practices to allow for successful revegetation of disposal areas. Additional spent shale research areas include roots studies, native tree and shrub establishment, heavy metal uptake and top soil requirements for long term vegetation survival and reproduction.

INTRODUCTION

Tosco Corporation, an industry leader and pioneer of western oil shale development, has been involved in reclamation research for over 15 years. This research has taken place at field locations in western Colorado and eastern Utah in cooperation with other oil shale industry leaders, the U. S. Forest Service and the Soil Conservation Service.

The stated goal of Tosco's mined-land reclamation has been to reclaim disposal and disturbed areas, to the extent possible, with native species of grasses, forbs and shrubs, and to promote a permanent and self-sustaining vegetation through proper reclamation techniques. It is Tosco's view that the proper selection of native and introduced species will enhance surface spoil stability, reduce erosion potential, improve the water balance, and help disturbed lands to return to a more productive and usable state within a shorter time period than reclamation with improper planning.

TOSCO'S PAST RECLAMATION EXPERIENCE

The first decade of reclamation research sponsored by Tosco Corporation and its venture partners in the Colony Development Operation (Colony project) were summarized by Bloch & Kilburn (1973). This was followed by an update of continuing reclamation research within Tosco Corporation along with a review of potential problems associated with spent shale disposal (Merino & Crookston, 1977). These are briefly summarized below.

Early studies established that spent shale from the TOSCO II process, which has a silt loam texture, is high in soluble salts and pH, and low in available phosphorus and nitrogen. Other mineral nutrients were low to adequate, but within the range found in soils in most of the western states (Baker, 1977). These data on physical and chemical properties were used to design both greenhouse studies and field tests of plant growth in order to identify potential species suitable for reclamation of processed shale.

The major problems encountered in establishing vegetation on processed shale are the shale's low fertility, poor infiltration rate, and high soluble salt content. However, studies have shown that applying phosphorus and nitrogen overcomes nutrient deficiencies and satisfactory growth is achieved (Berg, 1973a). The addition of potassium or micro-nutrients yields little, if any, additional response (Schmel & McCaslin, 1973). Comparison of water infiltration rates for native soil and various treaments of processed shale have been measured by McQueen (1963). The infiltration rates for native soil in the Piceance Basin have been measured at approximately 3 cm/hour on bare soils and as high as 7 cm/hour on soils with heavy litter cover (Meiman, 1973). Gifford (1971), showed that the addition of a soil or talus cover and the establishment of vegetation significantly increased the infiltration rates of the processed shale.

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[1] Paper presented at the Western Mined-Land Rehabilitation Research Workshop, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, June 10-11, 1982.

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Soluble salts, leaching, and resalinization of the embankment surface also have been the subject of much controversy with respect to spent shale disposal. Electrical conductivity determinations (which are a measure of salt concentrations) have shown that unleached TOSCO II spent shale averages 15 mmhos/cm. Because soluble salts in soils at conductivity readings greater than 4 mmhos/cm generally have adverse effects on seed germination, root penetration, and growth of crop plants, there was initial scepticism that processed shale which had not been leached of its soluble salts would support plant growth. However, studies performed on some plant species native to the semi-arid region of the oil shale country have shown them to tolerate soil salt concentrations many times higher than 15 mmhos/cm (McKell, et al. 1978).

To solve the problem of soluble salts in processed shale, Berg (1973b) advised leaching the surface with sufficient water to carry the salts well below the root zone. In later studies Harbert & Berg (1978) and Kilkelly, et al. (1981) have reported a good cover of perennial species on their TOSCO II test plots where initial leaching of surface salts was done. In contrast, Ferguson & Frischknecht (1979) have shown that vegetation can be successfully established on TOSCO II processed shale if suitable salt-tolerant and drought-resistant species are used. Over a 6 year testing period at Tosco's Sand Wash Project in eastern Utah 10 of 20 native plant species are growing successfully on unleached spent shale test plots.

The 1977-79 evaluation of the Colony revegetation test plots show that several species, especially fourwing saltbush, western, tall, crested and pubescent wheatgrasses, among others, not only have become well established in test plots but have also spread beyond their original plantings (Buckner & Kline, 1977; Merino & Kline, 1979; Buckner & Kline, 1980). In these 10 - 12 year old test plots, in addition to the success of planted species, other native forbs, grasses and shrubs are becoming established along the perimeter of many plots.

Placing a mulch cover atop processed shale has been found to be very important for seedling survival and for erosion control. Schmehl & McCaslin (1973) and Harbert & Berg (1978) have reported surface temperatures in excess of 50°C in processed shale exposed to solar heating. Since temperatures of this magnitude would inhibit germination and seedling establishment, it is necessary initially to use light-colored material such as a mulch for protection from the sun. To date, straw has proven to be the most satisfactory material and has been used extensively because of its availability and low cost.

Studies at the Colony Davis Gulch plots indicate that a minimal 12-inch cover of native soil or talus provides additional benefits not found with the mulching treatments (Frischneckt & Ferguson, 1979). In addition to reducing the problem of high surface temperatures and high runoff rates, a soil cover serves to hold moisture at the spent shale/soil interface. This increases the availability of water to planted species. Colony's evaluation of those study plots which have a 6-12 inch soil cover over spent shale indicate a more rapid establishment of a diverse vegetation cover than plots lacking soil over spent shale. A soil cover also aids in the visual blending of the disposal embankment into the surrounding terrain.

Shendrikar (1975) was possibly the first to analyze plant species grown on spent shale for trace metal content. In all, 18 plant species were compared to the same species grown in native soil. A 100% increase in concentration of a trace metal over that of native soil indicated a disposition to concentrate trace metals. All 18 species concentrated at least 2 of the 10 trace metals analyzed. Harbert & Berg (1978) found that vegetation grown on their spent shale revegetation plots tended to concentrate molybdenum and boron. Kilkelly & Lindsay (1979) investigated the trace element content of western wheatgrass and fourwing saltbush from Harbert and Berg's plots. Their results showed that of the five elements studied three could be discounted and boron and molybdenum required further investigation. This work has continued to the present (Schwab et al. 1980; Lindsay et al. 1981; Smith & Lindsay, 1982).

Of the 10 elements analyzed by Shendrikar (1975), six were essential trace metals of known nutritional value, and another three were possibly essential elements. Underwood (1977) states that the difference between an essential element and its toxic effects at various levels of concentration depends on a variety of factors including species of animal, target site in the animal and its age, chemical form of the metal, and other trace metals present. For example, molybdenum at 10 ppm can produce toxic effects in cattle, while 1000 ppm may be required to produce toxic effects in rats, chickens, or pigs.

Throughout Tosco's reclamation research an effort has been made to identify and solve all problems related to successful establishment of a self-sustaining vegetation cover. As stated earlier, these problems and available solutions included: (1) low fertility of spent shale improved by nitrogen and phosphorous fertilization; (2) poor infiltration rate of spent shale improved by mulching, soil cover, and vegetation establishment; and (3) high soluble salt content of the spent shale reduced by leaching, or avoided through a soil cover or the use of selected salt-tolerant species.

Studies from 1965 to the present have shown conclusively that with careful management of fertilization, mulching, irrigation and choice of plant species, a satisfactory plant cover can be established on processed shale. In all, over 100 species have been planted in our various study plots in Colorado and Utah and at least 25 species show good promise for reclamation.

CURRENT RECLAMATION ACTIVITIES

Tosco's current activities in mined-land reclamation are centered around the evaluation of field study plots established in 1976 in Utah and Colorado. These evaluations are on survival and growth of shrub species planted under different treatments of irrigation, soil cover and spent shale. With Tosco's very recent decision to divest itself of its 40% interest in the Colony project, planned reclamation research plots in western Colorado and at Tosco's research facility in Golden may be temporarily discontinued.

TECHNOLOGY GAPS IN RECLAMATION OF SPENT OIL SHALE

Tosco Corporation is confident that spent shale disposal areas can be reclaimed with a variety of native grasses and shrubs, depending on site location. But, because of the areal extent of a commercial disposal site (between 1,000 and 2,000 surface acres) adequate research is required prior to commercialization to assure a successful program. This research can be divided into the following topics: 1) reclamation planning; 2) spent shale and soil preparation and treatment; 3) hydrology, and 4) post-reclamation site management.

Under reclamation planning is included species selection for individual site characteristics. Elevation, slope, aspect, and precipitation, among others, are important considerations in species selection. Publications, such as those by Thornburg (1982) are a guide for reclamation planning, but there is a need to provide a comprehensive review paper on all research work in spent oil shale dealing with species selection. Several subtopics which should receive attention are: 1) disposition of roots of shrubs in spent shale; 2) techniques for establishing native shrubs and trees from mixed mountain shrub/aspen woodland vegetation types of western Colorado; 3) impact of heavy metal uptake by vegetation on biomass production, reproduction, longevity, and bioaccumulation in wildlife.

A preliminary study conducted for the Colony project showed that grass roots penetrated not much deeper than 24" from the surface whether in native soil or spent shale (Buckner, 1981). This study also suggested that grasses grown in spent shale had fewer emergent roots but more root biomass than grasses grown in native material. However, no field studies have been conducted on root biomass of shrubs grown in spent shale or topdressed spent shale. There has been some speculation that certain shrubs grow well in spent shale because their deep roots have penetrated the shallow spent shale of the test plots and the majority of root biomass is no longer in contact with the spent shale.

Studies on plant establishment in western Colorado and the Uintah Basin of Utah suggest that successful shrub species are mainly chenopods from the genus Atriplex. There is a need to determine establishment requirements in spent shale of species of the mixed mountain shrub/aspen woodland type where spent shale disposal areas are planned. Although a monoculture of Atriplex canescens within the mixed mountain shrub type may be permanent, it may not provide for the best land use in terms of aesthetics or wildlife habitat.

The topic of heavy metal uptake by plants grown in TOSCO II spent shale is being addressed by the Oil Shale Task Force, Center for Environmental Studies, University of Colorado. Their studies have shown that certain species tend to concentrate high levels of boron in leaf tissue. The extent to which these high boron concentrations inhibit yield is becoming better understood. However, boron effects on plant longevity and reproduction, and bioaccumulation in animals are still largely unknown for the oil shale region of Colorado and Utah.

The question of spent shale treatment and topdressing is also an area of conflicting viewpoints. The particular chemical and physical characteristics of spent shale are a function of the particular retorting technologies employed. Where the TOSCO II spent shale has a silty texture with a basic pH of approximately 9-9.5, Paraho spent shale is gravelly in texture with a pH closer to 11.5. These spent shale characteristics determine amendment strategies. Unfortunately, the literature has tended to treat all spent shales generically which has resulted in confusion and misunderstanding when attempting to determine treatments for spent shales. There is a need to establish soil amendment and topsoil requirements for spent shales representing each retort technology.

The hydrology and post-reclamation management of a spent shale disposal embankment are two important issues for resolution. Tosco has performed permeability analyses on spent shale and has monitored the moisture content with depth of its 40 foot deep semi-works embankment. These data suggest little or no moisture movement through the embankment. However, the total hydrologic balance of a reclamained TOSCO II spent shale disposal area is only in the preliminary stages of development. The Oil Shale Task Force, and other researchers, are actively engaged in preparing hydrologic models for disposal areas. Calibration of the models will require active participation of industry and outside research groups, each sharing the specifics of reclamation planning and results of studies.

Although post-reclamation management may appear straight forward, the question of "successful reclamation" is still open. The definition of this term is very likely different to industry, researchers and regulatory agencies. Post-reclamation management will be influenced to some extent by what constitutes a successful program in the eyes of the regulatory body which has jurisdiction over the particular mining activity. The size, particular shape and depth of a spent shale disposal area will dictate specific practices and techniques for monitoring pile stability, potential water movement into the pile, long term survival, reproduction and establishment of vegetation, and sediment control and irrigation systems.

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MINED LAND REHABILITATION RESEARCH AT

COLORADO STATE UNIVERSITY[1]

Edward F. Redente[2]

INTRODUCTION

The intent of this paper is to summarize the mined-land rehabilitation research program at Colorado State University. This will include statements concerning the mission of the University with respect to mined land rehabilitation research, a summary of reclamation research accomplishments during the past 10 years, a summary of current mined-land reclamation research projects, and finally an identification of technology gaps in the areas of topsoil storage and replacement, soil amendments, revegetation techniques, and plant material development.

MISSION STATEMENT

Colorado State University has a unique mission in the State of Colorado. The land-grant concept of a balanced program of teaching, research, extension, and public service provide the foundation for the University teaching and research programs, Experiment Station, Cooperative Extension Service, and Colorado State Forest Service. Mined land reclamation is one of many areas where a viable research program is maintained in order to discover, disseminate, apply, and preserve knowledge in this field of interdisciplinary studies.

RESEARCH ACCOMPLISHMENTS

Colorado State University has been actively involved in reclamation reasearch for well over 10 years. The academic departments on campus that have been primarily responsible for making contributions in the field include: Range Science, Agronomy, Botany and Plant Pathology, Microbiology, Earth Resources, Forestry, Fisheries and Wildlife Biology, Agricultural Engineering, and Civil Engineering. Many accomplishments have been made over the past 10 years; however, it is not possible in this paper to provide detailed information concerning all of the reclamation that has been accomplished at CSU over the past 10 years. The approach, therefore, will be to summarize some of the major accomplishments that have been made during this time period on research projects with which the Range Science Department has been directly and or indirectly involved.

Plant Growth Media

Research has shown that, in general, retorted oil shale used alone as a growth medium has not supported satisfactory stands of vegetation for stabilizing this material or establishing plant diversity for sustenance of domestic and wild herbivore use without large, long-term resource and management inputs. Retorted shale varies in texture from a silt loam to a gravelly sandy loam, from buff color to black, and is always high in soluble salts. These factors in combination with low fertility levels result in a plant growth medium that is not condusive to plant establishment. The black color promotes temperatures at the shale surface as high as 65°C during the summer months which is highly detrimental to newly emerging plants. The high salt content allows only the most salt-tolerant plants (halophytes) to inhabit the area. Studies show that some retorted shales produce a distorted or unnatural type of root which may affect normal plant growth and survival.

Topsoil covering does indeed moderate the detrimental effects of retorted shale material on plant growth but only for the species that are shallow rooted. Canopy cover and biomass from seeded plant mixtures show a decided increase with depth of topsoil over retorted oil shale. Topsoil coverings of 90 cm and 60 cm with 30 cm of gravel as a capillary barrier between soil and retorted shale appear to be better than shallower topsoil coverings. Shrubs and forbs because of their need for deeper root systems may eventually show less tolerance to drought and other natural environmental stresses when growing on shallow soils over retorted shale. Also, plants may concentrate toxic materials from the retorted shale into the aboveground plant material. These toxic elements are not only detrimental to normal plant growth (i.e., boron) but can cause severe physiological disturbances in the animal life as well (i.e., molybdenum).

The effects of rockiness in the plant growth medium which may appear on disturbed land where the topsoil is shallow and is underlain by parent material of sandstone and shale appears to favor the more arid, shrubby species over grasses. Such a soil profile has lower water holding capacity per unit of depth thus favoring the deeper rooted plants. However, with increased rockiness in the upper soil profile (90 cm) sites become more difficult to revegetate because of the poor seed-to-soil contact and the poor water holding capacity for seedling establishment. If frequent irrigation accompanies the seeding of rocky soils, grasses appear to compete rather successfully with shrubs; without irrigation these soils are a more favorable plant growth medium for deep-rooted shrubs.

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[1] Paper presented at the Mined-Land Rehabilitation Research Workshop, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

[2] Edward F. Redente, Assistant Professor of Range Science, Colorado State University, Fort Collins, CO.

As would be expected topsoil material is a better plant growth medium than subsoil for reestablishing seeded species and the rapidity with which native plants invade the area. The deficiencies of subsoil material as a plant growth medium can be partially overcome by proper use of fertilizer and water.

Seed Mixtures

Reclamation regulations have emphasized the use of native species in revegetating disturbed lands because of their natural evolution into established niches. Therefore, the importance of comparing native and introduced seed mixtures and combinations of these has been stressed in research projects at CSU.

In general, native shrubs produce better stands than native grasses or introduced grasses on arid sites. However, the addition of either fertilizer or water enhances the aboveground biomass of grasses under these conditions. Native and introduced grasses, when seeded with equal amounts of native and introduced forbs and shrubs, dominate more favorable sites. This domineering effect of grasses on favorable sites is increased by the addition of either fertilizer or water. This increase of grass production comes about at the expense of both forbs and shrubs in the seeded mixture. During the period of initial establishment (first two years following planting) the introduced grasses, on more favorable sites, are more competitive with seeded forbs and shrubs than native grasses. Introduced grasses appear to grow more rapidly at younger stages of establishment and therefore are more robust and occupy more space per plant than the native grass species, thus more nearly closing the community to invaders.

Most state and federal reclamation laws require the same approximate diversity of not only the preexistent plant species expression but for the life forms as well. To indeed accomplish this, seed mixtures become very important for each site to be reclaimed. Generally, increasing the amount of seed for one life form and decreasing the amount of seed for another life form will result in an increase in the one and a decrease in the other respectively in the revegetated stand. However, the stand that is obtained may not be proportionately related to the amount of seed for each life form in the mixture. For instance, on more favorable sites it may require twice as much shrub seed in the mixture to obtain even one-fourth shrub biomass in the total stand when compared to grasses. The reverse may be true on sites with rocky soils if grasses are to share in the plant expression up to as much as 25% of the total stand. Individual species within each life form are still more variable in their ability to establish in proportion to their inclusion in the seed mixture for various sites to be reclaimed.

Fertilizers

In most cases fertilizer (nitrogen) increases total herbage yield of seeded species compared to unfertilized plantings unless the rates of fertilizer are unusually high (>100#/A). It appears, in general, that seeded introduced species respond better to fertilizer applications than seeded native species. This is perhaps due to the adaptability of native species to low levels of nitrogen present in native soils.

Adding nitrogen to the soil, in most cases, increases the growth of grasses at the expense of both forbs and shrubs. This may be a desirable feature on areas with shallow topsoil and rocky substrate where grasses may be difficult to establish, or it may be an undesirable feature on favorble sites where it is desirable for forbs and shrubs to be major components of the established community.

Nitrogen fertilizer when applied on rocky soils shows an immediate effect upon grass growth and on shrubs only in later years after the nitrogen was believed to have leached down into the soil profile where deep-rooted shrub species could take advantage of it.

Irrigation

The addition of water should be used only when the final results can be predicted; otherwise, the ultimate expression of plants may be much different than expected from the general composition of the seeded mixture. Supplemental water during the first two years of establishment generally favors grasses over forbs and shrubs, but subsequent years without water may cause the grasses to decrease in favor of deep-rooted shrubs and forbs. However, grasses to become established in desirable quantities on arid sites may need irrigation water during at least the first growing season following planting. Likewise when establishing plant species of all life forms on desert sites, irrigation water may be needed provided the application of water is judiciously removed.

Microbial Activities

Microbial processes that take place in the soil are essential for reestablishing diverse and self-sustaining plant communities on disturbed lands. Many mechanisms essential to the cycling of chemical elements and the transfer of energy in disturbed soils could not operate efficiently without the presence of soil microorganisms. These are significant relationships between soil organic matter accumulation, availability of soil water, and nitrogen fixation rates when related to revegetation practices. With close monitoring of soil microbial activity and processes it is possible to identify those revegetation practices that will promote nutrient cycling most rapidly. Various soil microbial processes have also been valuable indicators for possible effects of capillary rise of soluble salts and certain trace elements on soil material placed over toxic spoils or waste material.

For most plants the formation of mycorrhizae (a fungus-root symbiosis) has been shown to be essential for normal plant nutrition in natural environments. This symbiotic fungal component (the mycorrhizal fungi) assists the plant in ion uptake, especially phosphorus, zinc, sulfur, calcium, and copper and by reducing plant water stress. Soil disturbance, including storage, may reduce the number of viable fungal spores present in the soil by dilution or by killing the spores which may alter the success of seeded vegetation. Thus, an abundance of mycorrhizal fungi and microbial activity is desirable for more rapid establishment of seeded plants on disturbed lands.

Plant Succession

When complex mixtures of several life forms and numerous species within each life form are seeded by various means, the eventual outcome of the plant expression will be determined only by the adjustments to stress over time. This is why long-term successional monitoring on revegetated areas is so important for future recommendations for mined land reclamation.

One of the more important considerations in choosing species for seeding mixtures is the selection of species that can complete their annual cycle and produce seed during most years. Otherwise, it has little chance of regenerating itself and maintaining a niche in the plant community. Many species are rather versatile and are said to be cosmopolitan because they adjust to many environments and are suited as revegetation species over rather broad areas. Other plant species, while appearing to be adapted over rather large regions, actually display ecotypes that are genetically different with respect to phenology.

Seeded introduced grasses during the initial stages of establishment appear more vigorous than native grasses and tend to occupy space at the expense of other seeded species. However, as time passes, it appears that many introduced grasses relinquish space to some of the native species.

Natural revegetation on areas with various degrees of soil disturbance showed that natural invasion was slow at best, and invading species were greatest on disturbed soils and least on severely disturbed soils. Plants that are nonmycorrhizal appear to be the first invaders on severely disturbed sites. Yearly environmental fluctuations (e.g., precipitation) and the severity of disturbance appear to be the primary factors in determining rates of natural invasion on disturbed sites.

Invasion affects seeded species by introducing a competitive factor in the survival scheme of seeded plants. In general, the degree to which a seed mixture closes the plant community to invaders the more effective the community is in controlling soil erosion.

An ideal seed mixture will minimize competition within the mixture while utilizing available soil moisture, nutrients, and incoming radiation that results in a desirable level of biomass production and sustained diversity. Understanding invasion as it relates to a seeded plant community is extremely important for selecting the seed mixture. Annual plant invaders were found most prevalently in seed mixtures consisting of only native species as compared to seed mixtures of introduced species or seed mixtures composed of both native and introduced species. This suggests that a mixture of both native and introduced species may be more desirable in controlling invasion of annual species during at least early stand development. However, in the long term the seeded native mixture may be more permanent and in time close the community to annual or ephemeral plants.

CURRENT RESEARCH ACTIVITIES

As mentioned in the preceeding section there are many departments at CSU that are involved in some aspect of mined land reclamation research. However, the current research projects that will be presented here are only those which involve the Range Science Department.

Most of the research that the Range Science Department is conducting or managing is oriented towards oil shale development. However, most of the research is of a generic nature and applies to reclamation activity throughout the arid and semiarid west. Specific reclamation research projects are listed below including an overall title and objectives associated with each research activity.

1. Effects of Plant Species, Soil Material, and Cultural Practices Upon Plant Establishment and Succession

The objectives of this project are directed toward the establishment of diverse, functional, and self-sustaining ecosystems with a minimum input of amendments. The specific objectives of the research include: (1) determining proper seeding practices of potentially usable mixtures of plant species and their relationship to cultural practices such as fertilization, irrigation, and mulching; (2) determining the rate and direction of plant succession on disturbed topsoil, subsoil, overburden, retorted shale, and retorted shale overlain by soil as influenced by natural invasion, species mixtures, and cultural practices; and (3) determining proper management procedures for long-term stabilization and reclamation of retorted shale materials.

2. Soil Microorganisms as They Affect Management of Mine Wastes and Reclamation of Disturbed Ecosystems

Specific objectives of this project include the following: (1) to evaluate microbial responses during reestablishment of plant communities on disturbed and revegetated soil, (2) to study the effects of soil storage on microbiological populations and on microorganism related nutrient cycling processes, and (3) to determine the effects of retorted shale materials on the microbiological characteristics of surface soils in relation to the development of plant communities on these materials.

3. Importance of Mycorrhizal Fungi in Revegetating Disturbed Soils

The overall objective of this project is to determine why there are differences in the potential of soils and mine waste material to form mycorrhizae and how these differences affect plant growth and plant community succession. This information will be important in formulating management techniques to best preserve or reestablish important microbiological processes in disturbed soils in semiarid environments.

4. Long-Term Fertility Study on Drastically Disturbed Land

The general objective of this subproject is to determine the long-term fertility requirements and methods of meeting these requirements on nitrogen- and phosphorus-deficient soil materials disturbed by mining activity. More specifically the objective involves comparing the usefulness of adding low to moderate annual applications of inorganic nitrogen fertilizer with that of adding high rates of inorganic nitrogen fertilizer only once at the initiation of the study on plant establishment and growth. Additionally, comparison of the effect on plant establishment and growth of the high rates of nitrogen fertilizer added initially with and without wood wastes was of interest. Other comparisons showing the effect of fertility treatments on plants were the addition of sewage sludge with and without wood wastes and four combinations of nitrogen and phosphorus fertilizer.

5. Ecogenetic Variability in Native Shrubs as Related to the Reestablishment of Vegetation on Disturbed Arid Shrublands

The primary objectives of this study are to: (1) evaluate the natural variation within species (especially shrubs) native to the Piceance Basin; (2) relate this variation to the environments which, through natural selection, produced it; and (3) make recommendations regarding source materials which can be expected to give longterm, natural success on particular sites.

6. Selection of Native Grasses and Legumes for Improved Rehabilitation

This research involves the development of improved plant material for the semiarid west by testing and selective breeding of a small number of important species. The improvements sought are in those traits important to early growth and land stabilization, such as seed size and lowered dormancy which contribute to rapid establishment and better seedling vigor, as well as the capacity to produce useful quantities of seed and the ability to fix atmospheric N_2 for legumes. This must be achieved without losing the ecological adaptation or altering the role played by these grasses and legumes in advanced successional stages.

7. Revegetating Disturbed Areas to Protect the Environment

The purpose of this study is to develop topsoiling guidelines for surface coal mine lands in the west. The primary objectives are to determine the optimum topsoil depth for returning disturbed lands to range-wildlife and agronomic uses. Various depths of topsoil over overburden are being studied in combination with overburden ripping, discing, and fertilizing.

TECHNOLOGY GAPS

Research in mined land reclamation has filled some voids in our knowledge, but because of the complexity of the discipline many technology gaps still remain. A field of study that must integrate information from such disciplines as ecology, plant physiology, soil sciences, soil microbiology, hydrology, engineering, wildlife biology, and biometry requires long-term research efforts to obtain reliable results. There have been a number of technology gaps identified by the research activities at CSU that apply to various types of mining activity and in general are applicable throughout the arid and semiarid west. Some of the more important voids in information are listed below.

1. Spoils Placement and Grading

   A. Regional guidelines for topsoil replacement depths for various land uses such as native range and agronomic.

   B. Minimum topsoil requirements for toxic spoil and waste material based on site specific environmantal conditions.

2. Mine Spoil Preparation and Treatment

   A. Development of methods for establishment of natural nutrient cycling with minimum inputs of organic and inorganic amendments.

   B. Revegetation practices and management techniques to maintain and promote essential soil microbial populations.

3. Planting and Planting Materials

   A. Development of an improved potting soil for containerized material that will promote better soil-water-root relationships in the field.

   B. Guidelines for combining species in complex mixtures of different life forms and competitiveness.

   C. Development and release of native cultivars, specifically native legumes and shrubs.

4. Wildlife and Fishery Habitat Management

   A. Identification of wildlife habitat requirements including topographic configuration, plant densities, and plant species composition.

   B. Biology of wildlife species, their habitat requirmeents and behavior as related to plant community structure.

BREEDING SUPERIOR PLANTS FOR DISTURBED LANDS[1]

Howard C. Stutz[2]

INTRODUCTION

In nature, newly disturbed areas become occupied by new species; only rarely can existing species accomodate new environments. Likewise, areas which have been disturbed by man can never be optimumally occupied by existing species; they too require genotypes specifically adapted to their unique challenges. As has always heretofore happened, left to itself, nature will ultimately provide adaptive species for mine spoils, and other disturbed sites but only after very long periods of time. With our current understanding of genetics and evolution, the same results can be obtained in a much shorter time-frame by using deliberate breeding and selection methods.

Breeding superior plants for disturbed lands is much like breeding domesticated plants. The same basic principles are involved and many of the same techniques are applicable. It involves mostly, the manipulation of already existing evolutionary processes and for the most part is done by simply accelerating evolutionary tempos.

PRODUCING NEW SPECIES

The five principle avenues for producing new species for such uses, or for improving existing species are as follows:

1. Assortment of new adaptative combinations from existing stores of genetic variation within species.
2. Acquisition of new mutations.
3. Segregation from gene pools enriched by intertaxon hybridization
4. Autopolyploidy
5. Allopolyploidy

Each of these may, independently, produce new adaptive species but most often new species or improved species come from a combination of two or more of them.

1. New mutations and existing stores of genetic variation (Illustrated by Atriplex canescens).

Although the impact of new mutations on evolutionary change is definably different from that of reassortment of existing stores of variation, distinguishing them in natural species is essentially impossible. Consequently these two avenues for speciation can be profitably lumped, at least in the initial stages of controlled breeding.

Each year thousands of acres of rangeland and mine spoils are sown with seed of Atriplex canescens. It is ordinarily provided by seed companies who collect it from natural stands. Almost never is the source requested nor provided and yet there is more genetic variation in Atriplex canescens than there is in most cultivated crops. It involves almost every conceivable morphological and physiological attribute. Some populations are diploid, some tetraploid, some hexaploid and some twelve-ploid. Some forms of Atriplex canescens grow to eight feet others to eight inches. Some are herbaceous root-sprouters, others are strictly caespitose woody shrubs. In a nursery at B.Y.U., Provo, Utah, many southern accessions cannot be grown because of winter frosts. Also, some northern forms do not flower, apparently because of their requirement for shorter summer nights than occurs in Utah. A. canescens from Utah and neighboring states produce two distinct forms of leaf: summer leaves which are linear and flat, 5-10 mm wide, 20-70 mm long and winter leaves which are involute and curled, 2-5 mm wide, 10-20 mm long. A. canescens from Arizona, Texas, Old Mexico, and other southern areas form only summer leaves.

With such extensive variation already available in Atriplex canescens, breeding superior forms which are uniquely adapted specifically to mine spoils or disturbed rangelands should be easy. Nature has already showed us the way.

2. Products of Intertaxon Hybridization (Illustrated by hybrids involving Atriplex canescens).

Species which receive genetic variation by way of hybridization are explosively

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enriched in comparison to receiving it by the slow tedious process of mutation alone. Consequently, for the most part, only plant species which frequently interbreed with others can survive in rapidly changing environments.

Atriplex canescens (four-wing saltbush) is the most widely distributed of all perennial species of Atriplex. Throughout it's range it contacts and hybridizes with almost all of the others. Natural hybrids have now been found between A. canescens and A. acanthocarpa, A. confertifolia, A. cuneata, A. falcata, A. gardneri, A. laciniata, A. obovata, A. polycarpa, A. spinifera and A. tridentata. In each case, hybrids are at least partly fertile, even when the chromosome numbers of the parents are dissimilar. Hybrid products are common and vary from subtle introgressants to very unusual recombinants. In some cases new adaptive products have become established as stabilized taxa.

The most common and widespread and probably important, stabilized segregant is A. aptera which has come, apparently repeatedly, from the parentage of A. canescens X A. gardneri. These tetraploid species meet and hybridize rather frequently throughout much of Montana, North Dakota, South Dakota and parts of southwestern Canada. Hybrid products are common and are easily identified in the field because of the many morphological differences between the parents. A. canescens is a woody shrub, with long linear leaves and fruiting bracts bearing four prominent "wings". A. gardneri is mostly herbaceous with a woody caudex and broader leaves and fruiting bracts with numerous cone-shaped protruberances. The hybrids are intermediate in all of these features as is A. aptera which appears to be a stabilized tetraploid product. A. aptera occurs along the tributaries of the Missouri River in Montana, Wyoming, North Dakota, South Dakota, Saskatchewan and Alberta. Although consistent in most major morphological features, it differs so much from site to site in character combinations that polyphyletic origins are suspected.

Since in nature, products from this hybrid are adaptive on a variety of sites throughout northwestern America, they could also furnish many other successful combinations. Variations among these hybrids is further compounded by between-site variations in both parents and could, predictably, be even further extended by bringing together for hybridization, parental types which have not yet had the opportunity to meet in nature.

Atriplex canescens X A. confertifolia hybrid products have already proven to be beneficial on some disturbed sites. Some of the segregants from this hybrid, grown in the nursery at Provo, Utah, closely resemble some of the natural populations of each parental species. At Garrison, Utah a population of A. confertifolia appears to have been enriched by introgression from A. canescens and at Honey Lake, California, a population of A. canescens appears to have been enriched by introgression from A. confertifolia. Some of the other natural variation in these species may have also come from such hybrids.

A. canescens X A. obovata hybrids are common near San Ysidro, New Mexico but because they are rare elsewhere, apparently occur only between specific parental strains. Because in this particular area the hybrids are fertile and yield a wide array of segregating progeny, a rich source is available for selection of new adaptive forms which may match some newly available niche.

A. canescens X A. tridentata hybrids, although involving parents having different chromosome numbers, are currently producing a number of new valuable, adaptive products in northern Utah and Nevada. Some of these may be immediately preadapted for occupation of newly available sites but even if not, the extensive variation found among the progeny appears sufficient to provide them.

From such extensive genetic variation combinations can, expectedly, be obtained which can accomodate almost any site.

3. Autopolyploidy (Illustrated by Atriplex confertifolia)

Although strictly homozygous autopolyploids derived from a single genome are probably rare or absent in nature, several have been reported which appear to have been derived from plants in which the component genomes are sufficiently homologous to permit good pairing during meiosis. Such polyploids will usually expectedly be at a disadvantage due to reduced fertility resulting from multivalent chromosome pairing at meiosis and may, because of imposed inbreeding, also show inbreeding depression. This, together with the usual absence of any major phenotypic advantage over parental diploids is probably why more have not been reported.

In Atriplex, however and in Artemisia and a few other shrubby genera, there is growing evidence that autoploypoidy may be common. Diploid, tetraploid and octoploid races of A. confertifolia, diploid and tetraploid races of A. corrugata and A. gardneri and diploid, tetraploid and hexaploid races of A. canescens and A. tridentata all appear to be autopolyploid series. Autopolyploid races of Artemisia have been reported in A. spinescens, A. ludoviciana and A. tridentata.

Phenotypic differences associated with autopolyploidy in shrubs are apparently sometimes adaptive. In Atriplex confertifolia, diploids are usually taller, coarser, more robust, with fewer heavier spines than the polyploids. They generally grow in association with juniper, sagebrush, and rabbitbrush and other species common to juniper and sagebrush communities. Tetraploids are smaller throughout, with finer- textured thorns and twigs. They usually grow in rather pure stands. Octoploids are even finer textured, smaller in stature and grow in even more uniform stands, often in almost pure culture.

The octoploids appear to be much more drought-and salt-tolerant and because of their numerous fine-textured spines, are probably less palatable than either diploids or tetraploids. Such differences permit A. confertifolia to occupy niches which would have otherwise been unavailable to it.

Although such correlation between phenotype and selective advantage is not always easy to identify, the very existence of autopolyploids in nature indicates that they have adaptive value and can consequently be profitably used for mined-land reclamation.

4. Allopolyploidy (Illustrated by Atriplex laciniata)

In contrast to autopolyploidy, alloplolyploidy is very common in nature. Some authors have suggested that nearly half of the flowering plants on earth today arose as allopolyploids. Such phenomenal success is apparently due to extensive heterosis made possible by the summation of two successful parents into one offspring. They are particularly successful in intermediate habitats and therefore may offer high potential for success in disturbed lands. Several allopolyploid species of Atriplex and Artemisia are among those which may be immediately valuable in reclamation efforts.

A distinctive form of A. canescens with laciniate bracts and hence named A. canescens variety laciniata is apparently an allopolyploid with 108 chromosomes derived from the parentage A. canescens X A. polycarpa. It is restricted to a relatively small area in the Mojave desert, from Barstow to the Salton Sea. It appears to be very drought-resistant and tolerates both sandy and heavy clay soils. When in contact with tetraploid A. canescens, natural hybridization between them is common. The hybrids are quite fertile and produce a variety of progeny most of which are also fairly fertile. Among these segregants, or similar segregants derived from similar artificial hybrids and polyploids involving more cold tolerant A. canescens from more northern areas, adaptive selections should be found with superb capabilities for accomodating mine spoils.

PROCEDURES

An ideal opportunity for demonstrating the feasibility of breeding superior plants for revegetating disturbed lands has been provided by Utah International Inc. at their Navajo Mine in northwestern New Mexico and by Northern Energy Resources Company (NERCO) at the Jim Bridger Mine in Wyoming. In cooperation with Arizona Public Service and Argonne National Laboratories, a genetic study has been initiated which has already identified several promising plant types for use on the mine spoils. The procedures being used appear to be satisfactory for producing superior species for use on any disturbed site including western rangelands.

Among the unique assets provided by the Navajo Mine and the Jim Bridger Mine are the batteries of harsh challenges which they harbor. They are situated in areas which normally receives only 6-10" annual precipitation, have temperature extremes of over 100°F. in the summer to below zero in winter and dry winds which blow almost incessantly. In such climates the sterile, salty, clay mine spoils are inhospitable to almost all known plants. Top-soiling, mulching, contouring and watering have helped but there are not yet any plants which are adequately adapted to these sites without supplemental support.

Because adaptive genotypes can be easily identified in these harsh conditions, the mine spoils provide an excellent arena in which to conduct breeding and selection studies. Although the same procedures can be used elsewhere to produce locally adaptive genotypes, for demonstration purposes, the backdrop of barren sterile spoils in forbidding climates at these mines is probably unequaled.

1. Selection of promising genotypes

Fortunately, it is unnecessary to begin breeding and selection studies "from scratch". Most disturbed sites can already accomodate some kinds of plants better than others. In order to find those plant materials which are most promising for use on a given site, a search is first made for species which come closest to occupying similar sites elsewhere. Because at these mines, the soils are mostly heavy salty clays and the climate severe, similar natural sites are the best candidates for harboring good preadapted germ plasm.

Throughout western North America there are numerous sterile, salty, clay hills and alkali flats which are much like the mine spoils. Almost the only plants which grow around these sterile islands, and which, in some places, encroach upon them, are members of the family Chenopodiaceae: Atriplex, Ceratoides, Grayia, Kochia, Salsola, Sarcobatus, Sueda, Zuckia. In each of these genera, except Atriplex, there are only one or two species. Atriplex, however, is genetically very rich. It consists of numerous species and varieties; several species contain chromosome races, interspecific hybridization is common. It is therefore a superb candidate for providing the necessary adaptive combinations for successful rehabilitation of the mine soils at both Navajo and Jim Bridger.

2. Experimental Plots

a. Selection ("S") plots

On the mine spoils, selection plots have been established in which many potential candidates for success have been planted both as seeds and as containerized transplants. The transplants are placed in rows with regular spacings to permit specific reference to each plant. The plots are fertilized and watered.

Horticultural challenges at each site are unique and important. At the Navajo Mine, in plots receiving supplemental water, competition with Salsola kali is severe; at Jim Bridger the main competitor is Halogeton. At other sites, the challenges may be different but the selection plot design appears to be suitable for any condition.

b. Testing ("T") Plots

As specific genotypes show superior performance in the "S" plots, they are introduced, as seeds and transplants, into a testing plot wherein each receives other treatments such as fertilizer and supplemental water. This not only provides an indication of their response to these various treatments but increases the population size of promising forms to a magnitude sufficient to minimize erroneous assessments promulgated by microenvironmental effects.

c. Selection-seed-increase ("SIS") Plots

Those genotypes which perform well in both the "S" and "T" plots are candidates for further selection and increase on a larger scale. This is accomplished by growing them in one-acre sized selection-seed-increase plots where favorable gene combinations have an increased opportunity to form and to be recognized. Into these plots containerized plants representing successful performers are given intense selection for a number of critical attributes while still maintaining high levels of genetic variation.

Because large quantities of seed will ultimately be required to sow acreages involved in revegetating mine spoils, machine harvestability is included as a principal requirement of selected products. To accomplish this, upon maturity plants in the "S-I-S" plots are mowed or harvested with a grain combine. Only those plants which respond favorably by subsequently producing another seed crop, are included in the selected product. Seed from a number of such plants are then used to initiate a second one-acre plot in which the same imposition of machine-harvesting is used. A third round of selection and machine harvesting follows and as many more rounds as necessary to provide a favorable product sufficiently uniform to permit characterization but still sufficiently variable to permit continued adjustment to environmental shifts.

In addition to machine-harvestability, attending selection pressures automatically include favorable germination, viability, vigor, capacity for establishment, disease resistance, response to local climatic conditions, etc. All of the necessary attributes for success are included because only the successful ones are perpetuated.

During this period of selection and seed increase, the harvest is available for inclusion in other revegetation seed mixes and appropriately monitored. Any outstanding performers among them are then, also, candidates for breeding and selection in "S", "T", and "SIS" plots.

PROGRESS AT THE NAVAJO MINES AND JIM BRIDGER

As anticipated, some of the species and some of the hybrid products introduced into the "S" and "T" plots have performed much better than others. Among those which were planted in the "T" plot at Navajo, A. canescens, A. tridentata, A. aptera and hybrid products from A. canescens x A. cuneata, A. canescens x A. obovata, A canescens x A. tridentata and A. canescens x A. polycarpa are among the best. At Jim Bridger, the top performers have come from A. canescens x A. gardneri, A. canescens x A. tridentata and A. gardneri x A. tridentata.

THE CHALLENGE

Because the rationale behind breeding and selection of superior plants for revegetation of disturbed lands is so simple, so straightforward, so predictably sound, it seems imperative that every mining operation should include such studies. It took a long time to incorporate formalized genetics into the breeding of domesticated plants and animals but since doing so, the rewards have been phenomenal. We need not plow that ground again. Having learned it's value and having discovered sound methodologies, there is no reason for further excluding it from any disturbed land management program. The costs are nominal; the rewards guaranteed.

RESEARCH CONDUCTED BY NORTH DAKOTA STATE UNIVERSITY ON THE RECLAMATION OF STRIP-MINED LAND

Gary A. Halvorson

Reclamation research at North Dakota State University (NDSU) was directed from Fargo by the Soil Science Department from 1974 through 1980. Because of increasing public interest in reclamation and because of the need for a broader-based research program the Land Reclamation Research Center (LRRC) was established in 1981 as a separate administrative unit to conduct and coordinate NDSU research in all agriculturally-related areas of reclamation. The LRRC is located at Mandan, North Dakota on the grounds of the Northern Great Plains Research Center. The objective of the LRRC is to develop and disseminate the "best available technology" for restoring lands that have been drastically disturbed or otherwise degraded as a result of strip-mining, oil drilling, or other land disturbing activity.

Accomplishments of Reclamation Research at NDSU

Soil and Overburden Characterization

Many aspects of reclamation have been covered by research at NDSU since 1974. Much of the initial research was directed toward characterization of the physical and chemical properties of soil and overburden. (Gee and Bauer, 1976; Schroer, 1976; Gee, Bauer, and Decker, 1978). These studies indicated that chemical and physical properties of overburden varied greatly with depth and within or between mine areas. (Schroer, 1976). Properties of reshaped mine spoil were found to be generally similar to those of the overburden in a mined area, but were usually averaged by the mixing process that accompanies reshaping of the spoil. As a result, there is generally less variation in properties within a 0 to 60 inch section of reshaped spoil than in a natural profile of that thickness. The need for a detailed soil map was emphasized as a tool necessary for determining the reclamation potential of areas proposed for mining. (Patterson, 1976). Properties of soil such as soil texture, bulk density, and sodium content were established as criteria for reclamation of mined land. (Omodt, Schroer, and Patterson, 1975).

Runoff and Erosion

A rainfall simulator was used to measure runoff and erosion from rangeland, spoil, and topsoiled sites (Gilley, et al., 1977). Greatest soil losses were on bare topsoil plots and least on the noncultivated rangeland site. Although a straw mulch reduced erosion on topsoil by over 90 percent, erosion and runoff values from the mulched topsoil sites were still over 50 percent higher than from the rangeland site. The erodibility of recently topsoiled sites was significantly reduced after vegetation became reestablished. (Gilley, 1980). Therefore, management techniques to maintain erosion and runoff losses within acceptable tolerance limits before vegetative reestablishment were seen as vital to successful reclamation of strip-mined land. It was suggested that soil losses could be minimized by shaping land to gentle slopes and revegetating as rapidly as possible (Gee, Gilley and Bauer, 1976).

Sodic spoil materials erode in a different manner than replaced topsoil. Specifically there was a consistent decrease in sediment loss resulting from cultivation at all sites (Gilley, et al., 1977). Because of the high sodium adsorption ratios (SAR) of the spoil, the non-cultivated plots had crusted, compacted, smooth surfaces. Cultivation broke the crusts and increased surface roughness. As a result of this increased surface roughness and an improved surface infiltration (Gilley et al., 1976) sediment loss was decreased. Nevertheless, the highly dispersive nature of the spoil material caused eventual surface sealing observed on the cultivated plots. The dispersion and surface sealing effects also resulted in a small effect of slope on erosion from spoil materials and apparent low rates of erosion from all sites.

Fertility Requirements

Fertility requirements of reclaimed land were studied at three different sites beginning in 1974. At two sites where corn and wheat were alternated in a continuous cropping pattern only modest improvements in yield resulted from the addition of phosphorus even though soil test values from these two sites for phosphorus were rated as "low".[1] Additions of nitrogen to one of these sites resulted in only modest increases in yield. The lack of response to nitrogen and phosphorus fertilizer at these sites was attributed to the lack of sufficient moisture to obtain yields which would strain the native fertility of the soil.

A mixed grass legume pasture on reclaimed land responded well to applications of up to 134 kg of nitrogen per ha.[2] Overall responses to phosphorus were poor although individual species did respond. Yields of crested wheatgrass increased with the addition of phosphorus while the yield of smooth bromegrass correspondingly decreased.

Topsoil Thickness Requirements

Some of the first research conducted by ARS researchers in North Dakota on stripmine reclamation identified the high sodium content of the spoil material as one of the factors most limiting reclamation of strip-mined land (Sandoval, et al., 1973). Recontouring of the spoil material was insufficient to return most mined-land to a productive

[1] Halvorson,G.A. [n.d.] Data on file North Dakota State University Land Reclamation Research Center, Mandan, North Dakota.

[2] Halvorson,G.A. and A. Bauer. [n.d.] Unpublished Data North Dakota State University Land Reclamation Research Center, Mandan, North Dakota.

condition. Early experiments focused on chemical reclamation or topsoil replacement as the best possible solutions. Grass seedlings were essentially a failure on sodic spoil using gypsum as a treatment whereas, up to a few thousand pounds of dry matter per acre were produced on spoil covered with two inches of topsoil (Power, et al., 1975). Gypsum improved dry matter yields on moderately sodic overburden, but two inches of topsoil produced over 4,000 pounds of dry matter per acre. Further evidence has been presented to show that chemical reclamation with gypsum produced results inferior to topsoil replacement (Merrill, et al., 1980b). Other work showed that theoretically calcium chloride, which is more soluble than gypsum could effectively reclaim sodic spoil material in North Dakota (Doering and Willis, 1975). For spoil material of SAR = 26, 66 tons/acre would be required to reclaim the top five feet of spoil material (Merrill, et al., 1980a). At an estimated cost of $98 per ton of $CaCl_2$, $32,500 per acre would be required for the $CaCl_2$ alone. It was concluded that replacement of topsoil provided the best and most cost effective method for mined-land reclamation where it was available (Merrill, et al., 1980b).

Further studies indicated that more than two inches of topsoil was required for maximum production of crested wheatgrass and a native grass mix (Ries, Sandoval, and Power, 1978). In an experiment conducted by North Dakota State University on moderately sodic overburden yields of wheat and corn were highest on plots reclaimed with the maximum topsoil thickness of 24", but were only slightly higher than yields on 12" of topsoil (Pole, et al., 1979). In 1974 a wedge experiment was initiated by USDA-ARS researchers at the Glenharold Mine in North Dakota. The wedge increased in topsoil thickness from 0 to 210 cm over spoil of SAR = 25. All crops studied responded to increased soil thickness up to a total of about 75 to 120 cm (Power, et al., 1981). Greatest yields of all crops occurred when about 20 cm of topsoil was placed over 55 to 110 cm of subsoil. With no topsoil only native grass produced yields over 75 percent of maximum. They concluded that 90 cm soil material is required to obtain maximum production of most crops under the conditions encountered.

In field trials on sodic spoil covered with up to 30 cm of topsoil high yields of crested wheatgrass were obtained initially. However, the yields progressively declined over a four year period (Sandoval and Gould, 1978). This decline in yield was attributed to a deterioration of topsoil quality due to the upward migration of soluble sodium from the spoil into the respread topsoil. Soil samples from the wedge experiment at the Glenharold Mine showed clearly that salt movement up into the replaced subsoil was occurring (ARS and NDSU, 1977; SEA-AR and NDSU, 1979). Merrill, et al., (1980b) deduced through theoretical considerations and laboratory experiments that much of the sodium migration could be explained by diffussion processes. They also postulated that when the hydraulic conductivity of the spoil is great enough to permit some seasonal leaching of soluble salts, sodification of the overspread soil will not be a problem. Research at another site in North Dakota with up to 24" of topsoil over moderately sodic overburden has given no indication of upward sodium migration (Pole, et al., 1979). The experimental results of the North Dakota experiments where sodium was moving upward suggested the need for replacing at least four feet of topsoil when available (SEA-AR and NDSU, 1979). These researchers recommended at least five feet of soil be present that "does not hinder root growth, water movement and storage". Present North Dakota regulations require the replacement of five feet of suitable plant growth material at all mines when it is available.

Current Reclamation Research

Topsoil and Second Lift Requirements

The question arose as to whether five feet of suitable plant growth material was needed to be replaced at all sites especially those sites with nonsodic overburden. In particular, much of the overburden just east of the Missouri River is composed of nonsodic glacial till.

A set of experiments was established in 1979 to evaluate, among other things, the thickness of topsoil required on three different textures of nonsodic overburden and whether the second lift (subsoil) was needed to return the land to optimum productivity. Eight trenches were excavated to a depth of fifteen feet. Four of the trenches were refilled with gravelly sandy loam (gsl), two with clay loam (cl) and two with silty clay loam (sicl) overburden. The second lift (cl) was replaced on two of the gsl trenches. The overburden for one trench of each overburden - second lift treatment was refilled using scrapers for maximum compaction. The remaining four trenches were refilled using front end loaders for minimum compaction and to simulate dragline reclamation. Topsoil was replaced on each trench at thicknesses of 9, 18, and 27 inches. Each trench was subdivided into two replications and each replication was further subdivided for fertility experiments. Similar undisturbed plots were located to the west and south of the trenches. In 1979 wheat was grown on the plots. Barley and corn were grown on the plots in 1980 and 1981, respectively.

The average yields from trenches filled with sicl, cl, or gsl+cl second lift were generally not significantly different from each other in a given year (Table 1). Therefore, the second lift was successful in returning land reclaimed over sandy loam overburden to a productive capacity equal to that of land reclaimed over finer textural overburden. Crop yields from trenches reclaimed using gsl overburden textures were significantly lower in every year except 1979 (Table 1). The yields of wheat, barley, and corn grown on the gsl filled trenches all increased significantly with increasing thickness of topsoil (Table 2). The crop yields obtained from 27 inches of topsoil placed on gsl overburden were statistically equal to or better than the yields obtained from the gsl+cl second lift filled trenches. In other words, the second lift did not add any statistically significant increases in productivity over what 27 inches of topsoil alone could provide as indicated by Duncan's New Multiple Range Test. Yields from trenches filled with gsl+cl second lift, cl, or sicl also generally increased with increasing topsoil thickness although these increases were not always consistent and often were not significant. In almost all cases yields were improved when the topsoil thickness was increased from 9 to 18 inches. Microtopographic effects were responsible for some of the inconsistencies in the data (Wollenhaupt and Richardson, 1982). There are three possible explanations for this increase in yields with increasing topsoil thickness. First, the gsl holds less water than the other finer textured overburden and may therefore, be creating a droughty condition in the soil. Since the cl textured topsoil holds more water than the gsl overburden adding more topsoil ought to increase the quantity of water available to the plant. Soil moisture data from access tubes in the trench plots clearly show that the gsl holds less total water during the entire growing season than the other finer textured materials. More detailed information in the coming year will be obtained to determine how much of the total soil water is readily available to the growing plant in the different trenches. A second possible explanation for the increasing yield with increasing topsoil thickness is the existence of a zone at the topsoil overburden interface which restricts root growth. Preliminary sampling of corn roots in 1981 showed clearly that roots were restricted from moving below the topsoil - overburden interface not only in the gsl filled trenches, but also in the trenches filled with finer textured overburden. A more detailed analysis of root growth will be conducted this year.

Table 1--Average crop yields for 1979-1981 grown on trenches filled with different textures of overburden.

Overburden texture	Wheat 1979	Barley 1980	Corn, 1981 grain	Corn, 1981 silage
gsl	15.2 a[1]	6.5 c	38 b	7.0 b
gsl+cl(2nd lift)	17.3 a	8.4 b	56 a	9.6 a
cl	17.0 a	8.3 b	53 a	8.9 a
sicl	15.9 a	10.0 a	57 a	9.9 a

[1] Numbers followed by the same letter are not significantly different from each other at the 0.05 level of confidence according to Duncan's New Multiple Range Test.

Other Current Research

Experiments are currently being conducted on a variety of topics related to mine-land reclamation. These include a study of the value of reclaiming prime agricultural soils seperately from non-prime soils. Various experiments are underway to study water movement in reclaimed profiles. Factors being monitored include soil water recharge over various overburden materials and topsoil depths and water losses due to evapotranspiration and deep percolation. Water use efficiency of crops grown on reclaimed soils is also being determined.

Table 2--Average crop yields for 1979-1981 grown on trenches filled with different textures of overburden and covered with three thicknesses of topsoil.

Overburden texture	Topsoil Thickness, in. 9	Topsoil Thickness, in. 18	Topsoil Thickness, in. 27
		Wheat 1979	
gsl	11.1 f[1]	16.1 cd	18.3 ab
gsl+cl(2nd lift)	15.1 cd	17.6 abc	19.2 a
cl	16.1 cd	17.0 bcd	17.8 abc
sicl	13.3 e	19.0 a	15.3 cd
		Barley, 1980	
gsl	4.0 f	6.9 e	8.6 cde
gsl+cl(2nd lift)	7.1 e	8.1 de	10.1 bcd
cl	6.8 e	7.7 e	10.3 abc
sicl	7.4 e	12.1 a	10.6 ab
		Corn grain, 1981	
gsl	25 f	39 e	51 cd
gsl+cl(2nd lift)	56 bcd	53 cd	58 bc
cl	42 e	50 d	66 a
sicl	53 cd	63 ab	56 cd
		Corn silage, 1981	
gsl	5.1 e	6.9 d	9.0 bc
gsl+cl(2nd lift)	9.1 bc	9.4 bc	10.2 b
cl	7.2 d	9.2 bc	10.4 b
sicl	8.1 cd	12.3 a	9.3 bc

[1] Numbers followed by the same letter are not significantly different from each other at the 0.05 level of confidence according to Duncan's New Multiple Range Test.

Reclamation Research Needs

Spoil Placement and Grading

Reclaimed Mine-Land Subsidence - Subsidence in the form of differential settlement affects land surface drainage which in turn may influence vegetative composition and growth. A relatively stable land surface is a prerequisite before evaluating biological production. In some cases appreciable settlement does not begin to show until five to seven years after spoil bank leveling.

Hydrology

Reestablishment of Groundwater Hydrology - The mining process severely disrupts the groundwater hydrology. In North Dakota the majority of the groundwater aquifers are the coal seams themselves. Exactly how the aquifers will reestablish themselves is not well understood and is of obvious importance to the kind of use the reclaimed land will be subject to.

Reestablishment of Surface Hydrology - Following reclamation most soil profiles are very dry. An understanding of how a moisture equilibrium is reestablished is vital to understanding what kind of vegetation will reestablish itself on the reclaimed land. Some research on this subject is underway, but much more from a wider geographic area is needed.

Soil Genetic Changes and Profile Development - How a reclaimed soil profile develops will have very important implications about the ultimate use the land is put to and its productivity. The accumulation of salts in certain horizons and the effect of such things as residual chunks of coal on soil properties will be of importance.

Salt Movement as Related to Soil - Water Landscape Relationships - Salt movement in reclaimed mine lands is of special concern since the spoil materials in North Dakota often contain relatively high concentrations of salt which can be detrimental to plant growth. Salt moves primarily in solution. The distribution and concentration of salts in reclaimed soils will be significantly affected by the soil - water regime which is a function of topography, parent material and climate. Many examples of this process exist in undisturbed soil landscapes.

Erosion and Runoff - Loss of soil due to erosion not only degrades the productivity of the soil due to topsoil loss and causes sedimentation problems in catch basins or streams but also results in more fertilizer use due to nutrients lost in the runoff. More information is needed to determine the validity of the Universal Soil Loss Equation on reclaimed soil.

Modelling of Crop Production - The law now requires that land following mining be reclaimed to a condition of "equal to or better" than it was before. Given the variety of soil types and variable climatic conditions, determining whether crop production following reclamation is equal to or better than production prior to mining is a difficult task. Modification of existing models for predicting crop production may serve as a useful tool in this area.

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WATER HARVESTING ON SURFACE MINE SPOILS[1]

John L. Thames and C. Brent Cluff[2]

BACKGROUND

About 500 acres are mined annually on the Black Mesa of Northern Arizona by Peabody Coal Company. The mines are within the Navajo reservation at an elevation of 7,000 feet where precipitation is only 10 or 11 inches a year and much of it occurs as snow. The area is dominated by juniper and pinyon pine and is heavily grazed by cattle, sheep, goats and horses.

The aim of Peabody's reclamation efforts is to return the mined sites to range lands. Their methods include regrading the spoil to slopes no greater than 15 percent, topsoiling to a depth of at least 6 inches, mulching, fertilizing, contour disking and planting a seed mixture of native species.

The methods used by Peabody are perhaps the best for establishing range lands in the area without resorting to irrigation. However there are several problems including (1) high costs ($12,000 to $20,000 an acre) in relation to the low economic returns from range lands, (2) the uncertainty of success due to the vagaries of precipitation which could delay vegetation establishment (even with reseeding) up to 8 to 10 years, (3) the lack of assurances that once the land is released back to the Navajo the excessive grazing presently practiced will not continue, and (4) perhaps most important, the loss of opportunity to diversify land use by providing alternatives.

Unfortunately, even with completely successful conversion of mine lands to good range lands little will have been done to improve income, nutrition and employment opportunities of the local people. With the increasing population on the reservation and the subsequent pressure on traditional family use areas, the single land use approach being taken might be a short-sited view; a view supported by the latter of the reclamation law.

It was believed that water harvesting (i.e. concentrating water from precipitation falling on a larger area for growing high value crops on a smaller agricultural area) could be incorporated with the conventional reclamation to provide diversity in land use, higher economic returns and greater social benefits with less risk and at no higher costs.

Water harvesting is at variance with the surface mining regulations in not regrading to original contour, not revegetating with native species, and in allowing permanent standing water on site. It also requires a knowledge different, but no greater, than that needed for managing livestock. Preliminary studies indicated that these disadvantages seemed to be outweighed by the potential advantages.

Accordingly, the Bureau of Mines agreed to fund a major water harvesting project on the Black Mesa in 1978. Peabody Coal Company provided a site and logistical support, and donated the use of heavy equipment with operators to develop the site.

SITE DEVELOPMENT

Orginally, a water harvesting system was to be designed for an ungraded site and to use the final cut at the high wall for water storage. However, the Surface Mining law, promulgated after the initial design had been made, required the reduction of high walls and prohibited the use of post regulation spoil areas for water harvesting. It was therefore necessary to choose a site among the available pre-regulation areas and to design a system which would minimize reshaping the topography of the already regraded spoil.

The final design of the water harvesting system (figure 1) consisted of (1) three water storage ponds with a total capacity of 800,000 gallons, (2) two leveled agricultural terraces of two and one half acres each,(3) an orchard 'road' catchment system of one acre which drained into the lower pond, (4) a fiberglass-asphalt-chip treated catchment of 8 acres, and (5) a salt treated catchment of 7 acres.

A system was installed to transfer water between ponds. In order to reduce evaporation water was concentrated as much as possible in the central pond which was partially covered by wax-impregnated styrofoam flats. Because of the high clay content of the spoil it was not necessary to seal the bottoms and sides of the ponds.

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[1] Paper presented at the Western Mined-Land Rehabilitation Research Workshop, Ft. Collins, Colorado, June 1-11, 1982.

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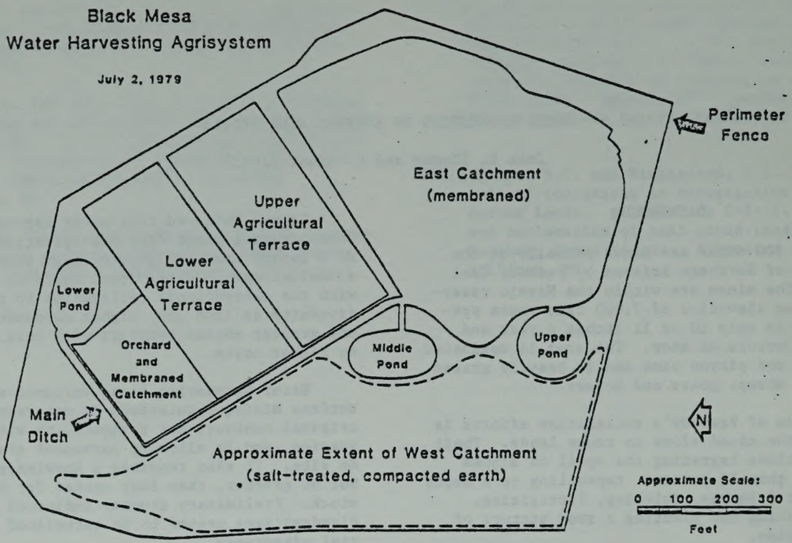

Black Mesa
Water Harvesting Agrisystem
July 2, 1979
Perimeter Fence
East Catchment (membraned)
Upper Agricultural Terrace
Lower Agricultural Terrace
Lower Pond
Orchard and Membraned Catchment
Middle Pond
Upper Pond
Main Ditch
N
Approximate Extent of West Catchment (salt-treated, compacted earth)
Approximate Scale:
0 100 200 300
Feet

Figure 1.--Site Layout

Contour drainages were constructed on the catchments to direct runoff water into the ponds. The drainages on steep slopes were paved with concrete to prevent erosion. It was originally thought necessary to use the expensive fiberglass-asphalt-chip treatment to help insure success, but it was found later that the simple and expensive salt treatment made an equally efficient catchment surface.

The agricultural terraces were irrigated from the ponds as often as necessary. Initially, flood irrigation was used, but because of problems with subsidence and the difficulty of maintaining dead level surfaces a sprinkler system was later employed. The orchard received runoff water directly from the 'roads' but was also irrigated as needed. In shaping the agricultural terraces it was found that about one-third of their areas toward the northeast had been covered with only a thin layer of spoil. The native soil material was then exposed during leveling. However, this provided an interesting comparison between spoil and native soil material. The system was operative one year after initiation. Crops have been grown for the past three seasons.

PRODUCTION-ANNUAL CROPS

With the exception of Indian corn there was not information available on vegetable crops that might be suitable to the area. Accordingly, the first two seasons were devoted to species trails and to improving the operation of the system.

Crops tested included beets, onions, turnips, potatoes, chard, lettuce, cabbage, tomatoes, squash, beans, pumpkins, mellons, mangles and corn. With the exception of tomatoes, all crops did surprisingly well, some producing at levels above the national average.

There appeared to be no differences in production between the native soil material exposed on the northeast ends of the terraced and the mine spoil. Chemical analysis indicated that salt content was high (about 1000 ppm) but levels (Fe, Mn, Cu, Zn, K, Pb, Cr, Hg, Cd, Se and As) minerals were well below toxic levels. Interestingly the mine spoil was developing a friable structure by the end of the third growing season.

During the last two seasons (1980 and 1981) some of the higher producing crops were planted. Results are summarized in table 1 and figure 2. Carrots did not perform as well as expected in terms of production per acre. The reasons for this lie mainly in the way the furrows were constructed. They were made deep and five-feet wide to allow walking on dry ridges and for better water distribution. However, the unplanted walkways covered about 1/3 of the area of the field; thus, the pounds-per-acre values underestimate the real productiveness and water-use efficiency. This is also true for the green beans and beets. Nevertheless, carrots yielded the highest return in dollars, even greater than those crops that exceeded the national production averages.

Table 1.--Varieties and Production, 1981.

	lbs.	lbs./ acre	$./ lb.	$./ acre
BEANS, GREEN, Topcrop Bush	945	4,474	0.275	1,230
BEETS, TABLE, Ruby Queen	1,820	14,259	0.08	1,141
CARROTS, Nantes Improved Coreless,				
mine spoil, early crop	2,350	20,151	0.10	2,015
mine spoil, late crop	4,698	14,113	0.10	1,411
topsoil, early crop	2,382	22,905	0.10	2,291
topsoil, late crop	3,501	17,942	0.10	1,794
CORN, SWEET, Early Sunglow				
mine spoil	1,497	5,443	0.10	544
topsoil	774	2,126	0.10	213
PUMPKINS, Small Sugar	5,625	32,845		
SQUASH, SUMMER, Early Prolific Yellow Straight-neck.	11,180	24,085		
WATERMELON, Sugar Baby	220	6,475		

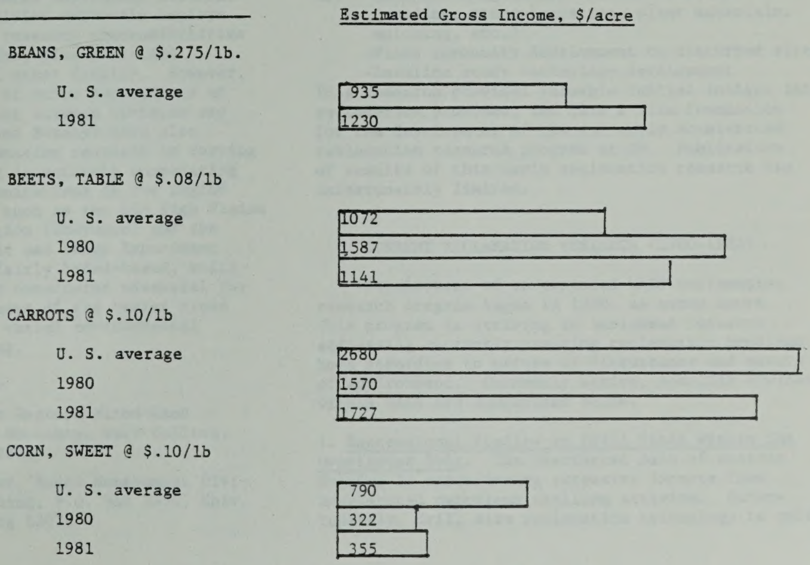
Green bean production was next highest in value and exceeded the national average by $295 per acre. This result is interesting since green beans are one of the more salt sensitive crops. Thus, they were not expected to perform as well as they did with the salt conditions of the soil materials. No differences in performance of beans were observed between topsoil and spoil areas.

Table beets also exceeded the national average (by $515 per acre in 1980 and by $65 per acre in 1981). There appeared to be no differences in productivity between the two soil materials. Beets are an uncommon food in the area, but requests by the local inhabitants greatly exceeded the supply.

The value of corn was the lowest of all crops. Production was less than half the national average. This was not unexpected, but corn is an important traditional food in the area, and was planted primarily for social reasons.

There are no data on the national production of squash and pumpkin. However, both are in demand and both exceeded each of the other crops in pounds per acre. Watermelon was planted because of local requests. Production was only fair as was expected from previous trails.

Figure 2.--Production Summary



PERENNIAL CROPS

Fruit trees had never been grown in the area before. Thus, several species believed to be suitable were planted that included two varieties of almonds, eight varieties of apples, two varieties of peaches, three varieties of pears and one variety each of chestnut and nectarine for a total of 68 plants. All trees were growing well after the third growing season. A few apple and peach trees produced large fruits of excellent taste, but it is too soon after only 3 growing seasons to determine the potential production of the varieties planted.

COSTS AND RETURNS

A comparison of conventional reclamation to the water-harvesting system shows both savings for the mining company and the individuals receiving the future stream of benefits from the reclaimed lands (table 2). A major reason for the savings is that the mining company and the Black Mesa inhabitants receive separable benefits. The company minimizes costs (primarily in not having to topsoil) and does not internalize the long-term revenues from the reclaimed land; the Black Mesa inhabitants do not realize the initial construction costs only the operating and maintenance costs.

The water-harvesting project yielded about $1,700 net revenues per cultivated acre in 1981. Agricultural yields are expected to increase when the orchard begins to bear and with further experimentation with annual crops, but the grazing potential is not expected to change.

Table 2.--Comparison of System Costs and Net Revenue, 1981.

	Conventional System	Water-Harvesting System
	------dollars per acre	---------
Construction	$11,260	$7,840
Operating Costs of system (PNV 10 yrs. @ 4%)	$2.11	$400[1]
Cropping Costs	--	$610
Income	$2.11	$2,200
NET REVENUE	$0.00	$1,190[2]

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[1] Estimated 4 to 1, catchment to crop ratio.

[2] Includes only crop acreage.

RECLAMATION RESEARCH THROUGH THE WYOMING AGRICULTURAL EXPERIMENT STATION, UNIVERSITY OF WYOMING: CURRENT STATUS AND FUTURE NEEDS[1]

Edward J. DePuit[2]

ORGANIZATION AND MISSION

Wyoming is a mineral-rich state, containing especially abundent reserves of coal, uranium, bentonite, trona and petroleum (including oil shale). The extraction of these minerals is drastically disturbing thousands of acres per year. The extent of such drastic land disturbance is expected to be maintained in coming years, despite current economic conditions. A justifiable concern over mitigation of adverse environmental impacts of mining has arisen in the past decade. The University of Wyoming (UW) has responded to this concern by means of an accelerated teaching, extension and research program in disturbed land reclamation. The following paper will summarize the research phase of this program, and will suggest areas of needed future research from the "Wyoming" perspective.

Because Wyoming is predominately a rangeland state, most impacts of mining are felt on range resources and reclamation goals usually call for re-establishment of rangeland for multiple land uses. Therefore, the reclamation research program at UW has been centered within the Range Management Division within the College of Agriculture/Wyoming Agricultural Experiment Station. The Range Management Division currently employs one faculty member with research responsibilities exclusively in reclamation, plus part-time commitments from several other faculty. However, personnel from a number of other departments at UW (most notably the Plant Science Division and Departments of Zoology and Botany) have also become involved in reclamation research in varying degrees. UW also has or is actively cooperating with other research organizations in the region on reclamation studies, such as the ARS High Plains Grasslands Research Station (Cheyenne) and the USFS Intermountain Forest and Range Experiment Station (Logan). This fairly broad-based, multidisciplinary approach is considered essential for proper research addressment of the varied types of mining impacts under varied environmental conditions within Wyoming.

Exclusive of faculty salaries, all support for reclamation research through the Wyoming Agricultural Experiment Station is through grant monies. The current shortage of such support has, unfortunately, to a certain extent limited the breadth of present research activities.

The broad mission of the reclamation research program within the Wyoming Agricultural Experiment Station (WAES) is to respond to the needs of Wyoming's mineral industry and regulatory agencies for improved applied methods to achieve required land reclamation goals. The following paragraphs will briefly describe past accomplishments, present status and future needed directions of research activities pursuant to this stated mission.

PAST RESEARCH ACCOMPLISHMENTS (1970-1980)

UW reclamation research accomplishments during the 1970's were limited by lack of formal support. However, under the direction of two former Range faculty members, M. May and R. Lang, important initial progress was made. The emphasis of this early research was primarily on coal and uranium surface-mined lands, and concentrated on such areas as:
- Applied revegetation cultural practices (seeding, transplantation, plant materials, mulching, etc.)
- Plant community development on disturbed sites
- Baseline study technology development

This research provided valuable initial insight into reclamation problems, and laid a firm foundation for the development of the currently accelerated reclamation research program at UW. Publication of results of this early reclamation research was unfortunately limited.

CURRENT RECLAMATION RESEARCH (1980-1982)

Development of an expanded WAES reclamation research program began in 1980, as noted above. This program is striving to implement research addressing currently pressing reclamation problems both according to nature of disturbance and nature of environment. Currently active, specific studies within WAES are summarized below.

1. Successional Studies on Drill Sites Within the Overthrust Belt. The Overthrust Belt of western Wyoming is experiencing extensive impacts from accelerated petroleum drilling activity. Unfortunately, drill site reclamation technology is still

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in its infancy. In 1981, a research project was initiated (through the USFS Intermountain Forest and Range Experiment Station) to investigate drill site plant community development on a series of 90+ abandoned drill sites within the Bridger-Teton National Forest as influenced by site biophysical characteristics, time and applied reclamation practices. The ultimate goal of this project will involve development of improved recommendations for applied reclamation practices soundly based upon a knowledge of successional processes and causal factors. This project is scheduled for completion by June, 1983. (UW investigator: E. DePuit).

2. Successional Studies on Orphan Spent Oil Shale Sites in Central Colorado. Although considerable research has been conducted on initial reclamation practices and short-term plant community development on spent oil shale in central Colorado, relatively little is known on long-term successional patterns. To this end, a study (funded by Tosco Corp.) was initiated in 1981 to investigate current successional status of a series of spent shale sites in the Piceance Basin abandoned in the 1920's which had undergone natural plant community succession for roughly 50 years. Results of this research will hopefully relate varied plant community development to variations in site biophysical characteristics, and thereby allow proper refinement of currently developed initial spent shale reclamation practices in light of anticipated long-term successional development. This study is scheduled for completion by mid-summer, 1982. (UW investigator: E. DePuit).

3. Effects of Varied Mulch Method, Fertilization Regime and Topsoil Depth on Revegetation of Uranium Mined Lands. In 1978, a study was initiated on uranium mined land in central Wyoming by the ARS High Plains Grasslands Research Station to evaluate effects of stubble vs. straw mulching, single vs. repeated N fertilization and varied topsoil depth (0 to 30 inches) on revegetation. In 1981, UW became cooperatively involved in the third year of monitoring of this study. An interim progress report summarizing effects of treatment variables on vegetation and soil development over the first three growing seasons will be completed by mid-summer, 1982. The study will continue to be monitored for at least another two years. (UW investigator: E. DePuit).

4. Effects of Sawmill Wood Residues on Revegetation of Bentonite Mined Lands. Bentonite mining offers unique, challenging reclamation problems in our region due to the nature of spoil materials, and has been relatively little researched in comparison to other types of mining. In 1981, a cooperative study between UW, ARS and the Wyoming State Forestry Division (funded by the Wyoming Department of Environmental Quality) was initiated to evaluate the feasibility of use of sawmill wood residues as a soil amendment to improve revegetation of orphan bentonite spoils near the Black Hills. Treatment variables included four residue application rates (0, 40, 80 and 120 green tons/acre), four N fertilization rates per residue treatment (0, 5, 10 and 15 lbs. ammonium nitrate/ton residue) and two different seed mixtures. This study is scheduled for completion by December, 1983. If results are positive, the study will have aided in resolution of two environmental problems: bentonite mined land reclamation and disposal of sawmill residue in an ecologically acceptable manner. (UW investigator: E. DePuit).

5. Effects of Surface Manipulations on Reclamation of Coal Surface Mined Lands. Benefits of various surface roughening techniques on mined land revegetation and hydrology in arid/semiarid regions have frequently been noted. In 1981, a cooperative project between UW and the USFS Intermountain Forest and Range Experiment Station was initiated to evaluate effects of four surface treatments on reclamation of a topsoiled coal surface mine site in the Powder River Basin of Wyoming. Four surface treatments - deep chisel plowing, gouging, contour furrowing and crimped straw mulch (control) - were implemented. Both vegetation and soil moisture responses to these treatments will be monitored over a two to three year period, with project completion scheduled for 1984. (UW investigators: J. Dodd/E. DePuit).

6. Establishment of Arid/Semiarid Land Shrubs via Direct Seeding. In cooperation with the ARS High Plains Grasslands Research Station, UW researchers are investigating methods for the difficult task of establishing shrubs on mined land sites by direct seeding in an ongoing project. The greenhouse and field germination ecology of Gardner saltbush has comprised the specific initial emphasis of the UW phase of this project in 1981-82, although several other shrub species are also being investigated. Completion of the initial phase of this study is scheduled for 1983. (UW investigator: R. Abernethy).

FUTURE RESEARCH NEEDS

The following paragraphs summarize the WAES perception of high priority areas in which future reclamation research progress is especially needed (i.e., where current technology is most lacking). These areas will be discussed/listed with reference to "environment" of disturbance, type of disturbance and according to reclamation technological area.

Environment of Disturbance

Past reclamation research in our region has been most extensively conducted, and reclamation progress (appropriately) most pronounced, within semiarid grassland environments (e.g., the Northern Great Plains area). Relatively less attention has been given to or progress made in reclamation of disturbances in the more harsh environments offered by arid and high altitude lands. The adverse climatic and/or edaphic constraints to reclamation in such environments require greatly accelerated research emphasis if impacts of mineral extraction are to be properly mitigated. Under existent reclamation technology, proper reclamation of arid/high altitude disturbances (at least over the short-term) is still an "open" question.

Type Of Disturbance

With respect to type of mineral extraction-related disturbance, surface coal and uranium mined lands and surface-deposited spent oil shale lands have received most research attention in the past decade, and progress has been correspondingly great. While the technology gaps still evident for reclamation of the above types of disturbance certainly warrant continued research, future research should be more strongly directed toward addressment of other types of drastic land disturbance as well. A number of significant forms of disturbance have, as yet, received only minimal overall research emphasis; in Wyoming, chief among these are:

1. Bentonite Mined Land Reclamation. Bentonite mining disturbs extensive areas, and reclamation progress has been seriously hampered by edaphic and, occasionally, climatic constraints. Although some research has been and is being conducted, far greater emphasis is needed.

2. Drilling Activity Reclamation. Drilling disturbances, as opposed to those of mining, are extensive rather than intensive in nature, and pose unique reclamation challenges. Little or no research has been conducted specifically on reclamation of drill sites and associated access roads. In view of the current and anticipated extent of such disturbances, it is important that this technological void be filled.

3. Tailing Reclamation. Tailing materials produced by processing of various mineral ores in our region (e.g., heavy metals/rare earth minerals, trona, uranium, etc.) frequently contribute to extreme localized reclamation problems due to physical and/or chemical characteristics. While some research has been conducted on reclamation of such disturbances, it is felt that more is warranted.

4. Pipeline/Powerline Corridor Reclamation. While not in themselves a mining disturbance, pipelines and powerlines are often associated with mineral extraction. In certain cases, acreage disturbed by pipeline/powerline corridors may far exceed the area directly impacted by mining. Similar to drilling activity, pipeline/powerline corridor impacts are extensive in nature, and have at present been only minimally researched with respect to reclamation. The unique aspects of corridor reclamation therefore deserve future research emphasis.

Reclamation Technological Area

Future research needs may also be categorized and prioritized according to "Technological Area". The following are major, specific areas of reclamation technology which, in the perception of WAES, deserve increased research addressment in future years. Especially critical areas are noted with an asterisk (*).

1. Reclamation Planning. Major needs:
   - Improved design of reclamation plans to properly address proposed future land uses (including integration of multiple uses, if appropriate).
   - Improved coordination of reclamation and mining plans.

2. Spoils Placement and Grading. Major needs:
   - Research on the need and methods for isolation of inimical spoil below the plant root zone.
   - *- Spoil handling/replacement methods to facilitate reestablishment of site sub-surface hydrological systems (see also 'Hydrology' below).
   - Improved grading methods for reestablishment of topographic configurations conducive to proposed land uses (e.g., wildlife habitat vs. grazing land vs. cropland, etc., or a proper combination of such).
   - Research on alternatives to the fill method for highwall reduction.

3. Minespoil Preparation and Treatment. Major needs:
   - *- Practical applied methods for alleviation of salts problems in soils/spoils in arid and semiarid areas.
   - Further refined topsoiling procedures (e.g., methods for creation of edaphic diversity, effects of multiple lift topsoiling, etc.).

4. Planting and Planting Materials. Major needs:
   - *- Improved methods for achieving alpha (intra-community) diversity - with respect to species, life forms and seasonality.
   - *- Improved methods for achieving beta (i.e., habitat) diversity among plant communities.
   - Further research on temporary irrigation for initial vegetation establishment.

5. Hydrology (Surface and Subsurface). Major needs:
   - Improved methods for steep slope stabilization and erosion control.
   - Alluvial valley floor reconstruction technology.
   - *- Definition of impacts of mining on subsurface hydrology (deep water movement, aquifer characteristics, etc.) and development of applied materials handling methods to mitigate any defined adverse impacts.

6. Post-Initial Reclamation Activities.Major needs:
   - *- Development of applied management practices (e.g., grazing systems, burning, mowing, haying, etc.) specifically tailored to mined land conditions for protective, corrective and/or manipulative functions.
   - *- Long-term monitoring of effects of initially applied reclamation practices on mined land ecosystem development (e.g., plant community succession, soil development, subsurface hydrology, etc.).
   - *- Refinement/improvement/clarification of state/federal regulatory reclamation performance standards and evaluation procedures.

SUMMARY

This paper has attempted, in cursory fashion, to acquaint the reader with the nature of past and present reclamation research activities within the Wyoming Agricultural Experiment Station, University of Wyoming. Perhaps more importantly, it has also given specific examples of areas in which future research will be essential if current gaps in reclamation technology are to be filled.

We feel that major progress has been achieved in western mined land reclamation technology in the past decade, but that, nonetheless, land reclamation is still at best imperfectly understood. It is the responsibility of the research community to assure that the pattern of progress of the past is maintained and properly directed in the future. This responsibility can be best met through an atmosphere of improved communication and cooperation/coordination among the various research organizations in our region. This workshop represents one excellent approach to fostering such an atmosphere.

RECLAMATION RESEARCH ON COAL MINE SPOILS

BY NEW MEXICO STATE UNIVERSITY[1]

Walter L. Gould[2]

INTRODUCTION

The major deposits of coal in New Mexico at a depth that are economically feasible to mine by surface mining methods are located in the San Juan Basin in the northwestern corner of the state. Over 90 percent of the strippable coal in New Mexico is found in the Fruitland Formation.[3] The climate along the exposure of the Fruitland Formation in San Juan County is semi-arid with an average annual rainfall varying from about 15 to 25 cm and yearly amounts varying from 8 to 45 cm and seasonal distribution is very erratic. The amount and type of vegetation varies with soil type; sandy and loam soils are most productive and saline-sodic clays are frequently barren of perennial species. Overburden materials from the Fruitland Formation are mostly sodic shales and sandstone.

Major concerns toward reclamation by NMSU scientists in San Juan County were: (1) irrigation needs and scheduling, (2) depth of topsoil, (3) mulching needs, (4) fertilization, (5) soil amendments on sodic or carbonaceous spoils, (6) microbial activity, and (7) use of saline water.

SUMMARY OF RECLAMATION ACCOMPLISHMENTS

Irrigation

A National Academy of Science publication[4] suggests that areas in the western United States which receive less than 25 cm of annual precipitation may require irrigation in order to establish a suitable stand of adapted species. Seedings were made on graded spoil with and without a topdressing of sandy soil in 1974 and 1975, and on a plot of disked sandy rangeland in 1973 and 1974 at the San Juan Mine. Individual rows were seeded to a single species. Essentially no plants emerged in the non-irrigated plots on the mine spoil either with or without topsoil, while moderately good stands were attained with irrigation on topsoiled plots. Heavy rainfall during the winter of 1973-74 produced a very dense stand of Indian ricegrass on the rangeland plots, but few plants survived the droughty summer season that followed. Possibly the mortality of Indian ricegrass would have been less if the initial stand had not been so dense. Very few plants of other species emerged. The results indicated that under the rainfall conditions existing at the San Juan Mine, the likelihood for successful revegetation in a reasonable period of time without irrigation is very low in most years.

Two experiments were carried out to determine the optimum scheduling of irrigation for emergence of native plant species. No rainfall events occurred during the first test. Treatments included applications of 1.3 or 2.5 cm of water at 1, 2 or 3-day intervals to a Fruitland loamy sand over sodic spoil. The best stands were obtained with daily applications of water or the application of 1.3 cm on alternate days following an initial application of 5.0 cm to bring the topsoil to field capacity. Poor emergence resulted when the interval between irrigations exceeded two days. In the second test, a three-day period of cloudy weather with light rain showers occurred four days after seeding. Good stands were obtained in all plots.

An experiment was conducted to determine irrigation needs after a stand of native species has emerged. Treatments included application of 2.5, 5.0 or 7.5 cm of water at intervals varying from 10 to 21 days. Plant height and stand density were evaluated at the end of the growing season. Water stress was evident at the lower rates of irrigation and when the interval between irrigations was 3 weeks, even though the same amount of water was applied as when irrigations were 2 weeks apart. Satisfactory growth was obtained with all irrigation treatments, but the growth in plots irrigated with 5.0 cm of water at 14-day intervals was significantly greater than 2.5 cm applications every 14 days or 7.5 cm applications at 21-day intervals.

Topsoil depth

Experiments were conducted in several years to determine the quantity of topsoil needed over sodic-saline spoils for favorable growth of native range plants. Topsoil depths varied from zero to 120 cm. In some tests 10 cm of soil was incorporated into spoil by disking and 10 to 30 cm of additional soil was applied over the soil-spoil mixture. Few plants were established on plots with no topsoil. While under irrigation, the growth of most species increased as the depth of topsoil increase until the topsoil depth reached about 45 cm. After irrigation was withdrawn, plant growth was as good at 60 cm as at greater depth when topsoil was placed on graded spoil without mixing. With the soil-spoil mixtures, plant growth was as good or better in plots receiving an additional 20 cm of soil as in plots receiving 45 cm or more when there was an abrupt change at the soil-spoil interface.

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[1] Paper presented at the Western Mined-Land Rehabilitation Research Workshop, Fort Collins, Colorado.

[2] Walter L. Gould, Associate Professor, Agronomy Department, New Mexico State University, Las Cruces, New Mexico 88003.

[3] Strippable low-sulfur coal resources of the San Juan Basin in New Mexico and Colorado by J. W. Schomaker, E. C. Beaumont, and F. E. Kottlowski (eds). 1971.

[4] Rehabilitation Potential of Western Coal Lands—A Report to the Energy Policy Project of the Ford Foundation by J. P. Lippincott, Carbridge, MA.

Mulching

Grass hay or straw mulch was applied at rates of 1000, 2000, or 4000 lb/ac in five tests. In all tests the mulch was crimped into the soil or spoil. In two tests the mulch was also incorporated into the soil with a rototiller. Under irrigated conditions plant stands in spoil material were greater in plots with mulch than in non-mulched plots but in plots with topsoil the application of mulch generally had no effect or a deleterious effect on grass stands. The stands of grass in unmulched plots were generally not significantly different than in mulched plots, but there was a trend for an inverse relationship of stand density and quantity of mulch. Stands of grain, weeds, or non-adapted species that developed from seed inadvertently applied with the mulch had a deleterious effect on growth of desired grass species. Fourwing saltbush was the only species that consistently responded favorably to a mulch treatment. Under non-irrigated conditions, hay mulch crimped into the sandy soil effectively inhibited wind erosion. However, the effect on plant establishment was not evaluated because the droughty conditions precluded plant emergence.

Fertilization

The soils in the San Juan Basin are generally low in nitrogen and available phosphorus. Overburden materials above the upper coal seam in the Fruitland Formation may be low or very high in nitrogen, and strata below the upper coal seam is consistently low in nitrogen. Available phosphorus is generally low in overburden materials.[5] In greenhouse studies the growth of native plants was significantly increased with fertilization in the sandy soils common to the exposure of the Fruitland Formation. Growth and vigor increased as the rates of nitrogen and phosphorus increased to 100 and 400 lb/ac, respectively. However, drought tolerance was reduced as the rates of fertilizer increased. In the field, a positive response to fertilization was observed in only one of five experiments. In the experiment where a positive growth response was observed, sandy topsoil was placed over spoil or a soil-spoil mixture at depths of 0 to 30 cm. Plant growth was significantly greater in fertilized plots with 30 cm of topsoil than in non-fertilized plots, but the difference in growth between fertilizer treatments was reduced as topsoil depth was reduced. The difference was insignificant with 10 cm of soil over the soil-spoil mixture.

Soil Amendments

Coaly spoil derived from carbonaceous shales or mixtures of waste coal and mineral spoil exhibited water repellance during irrigation. An experiment was run to observe the effect of three surfactants, lime, bottom ash from a coal-fired power plant and topsoil on plant establishment and growth in coaly spoil. One surfactant apparently was effective in reducing the surface tension of water so that infiltration was increased, but the water was not retained by the coaly spoil. Covering this spoil with 20 cm of soil was the most effective treatment in promoting plant emergence and growth.

Sodic sandstone and shale spoils were treated with concentrated sulfuric acid at rates of 0 to 5 tons per acre, gypsum, agricultural sulfur, bottom ash, or topsoil to determine the effects of these treatments on the electrical conductivity and sodium adsorption ratio (SAR) of the spoil at various depths and on plant growth. Leaching was necessary on the plots treated with sulfuric acid before plants would become established. Very low emergence of seedlings was obtained on plots covered with 5 cm of bottom ash. The best emergence and growth of native species were on plots receiving topsoil. Incorporation of bottom ash or topsoil with sodic spoil and topdressing with 10 cm or more of topsoil made an acceptable seedbed.

Two years after irrigations ceased, good stands of native plants remained where 7 cm or more of topsoil was placed over gypsum-treated sodic spoil, in contrast to the need for approximately 40 cm of topsoil without gypsum. Results from several studies indicate that revegetation of coaly or sodic spoils can be successful if 10 to 15 cm of soil is incorporated into the spoil and 15 cm or more of soil is placed over the mixture. Gypsum treatment will enhance water movement and root growth into sodic spoil, and may reduce the quantity of topsoil required.

Microbial activity

Sodic spoil from the San Juan Mine was amended with topsoil, alfalfa hay and sewage sludge in the greenhouse and in the field. In the greenhouse organic amendment increase fungal diversity and population, and nitrification potential in both rhizosphere and non-rhizosphere soil. The topsoil amendment had no effect on microbial activity. In the field, organic amendments increased Fungi diversity, number and activity (as measured by dehydragenase) only in non-rhizosphere. Azotobacter numbers were increased in the rhizosphere. Topsoil amendment alone did not affect microbial activity in the field.

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[5] Chemical and physical properties of core samples from a coal-bearing formation in San Juan County, NM by D. Rai, P. J. Wierenga, and W. L. Gould. 1974.

Irrigation with saline water

Surface water is not available for reclamation except along the San Juan River, so groundwater may have to be used for revegetation. Groundwaters tend to be saline ($EC \geq 4.0$) and sodic ($SAR > 15$). Experiments were conducted in the laboratory and greenhouse to determine the effect of water quality on plant emergence and growth, infiltration, and soil properties. Irrigation waters were synthesized to simulate groundwater and these were compared with tapwater relative to the various parameters. Groundwater from a well in the coal field was compared with tapwater on the growth of plants and the effect on infiltration.

In a laboratory test, the infiltration rates of a given soil irrigated with various qualities of saline-sodic water were the same with all waters, but soils of different texture had wide differences in infiltration. Application of distilled water (simulating rain) caused a sharp reduction in infiltration. Very sandy soil irrigated with sodic water and distilled water had a sharp reduction in infiltration, but the infiltration rate remain satisfactory. Clay soil became nearly impervious.

There was a buildup of salt in the surface 2.5 cm of soil after irrigation with saline water. Plant emergence and growth was significantly reduced by the most saline water ($EC = 12$ mmhos/cm and $SAR = 68$). Satisfactory growth occurred in a sandy loam soil irrigated with saline water from a well ($EC = 4$ mmhos). The application of gypsum at ½ to 1 ton per acre as a surface treatment was effective in maintaining a good infiltration rate when rainwater was applied after the saline water. Water with the quality of the waters tested will probably be satisfactory as irrigation water, but they should be used sparingly.

Summary of current research activity

Currently, no funding is being provided for reclamation research at New Mexico State University. Experiments put out in previous years will be monitored one or two times annually to determine long-term effects of treatments.

Technology gaps listed in order of decreasing importance

1. Post-reclamation site management

It has been demonstrated in Arizona (Black Mesa) and New Mexico that livestock management is necessary to maintain stands that have been established. Old seedlings near Gallup, NM were primarily with introduced, mid- and tall-grasses, while recent seedings were with native plant species. How well these vegetation types will hold up and what type of management is necessary needs to be determined. In San Juan County where all seedings are with native species, management strategies need to be developed.

2. Spoils placement and grading

Especially on badland sites where the quality of the surface soil is so poor that it is unsuitable as growth media, selective placement of overburden may significantly improve the final minesoil. Separation of certain sandstone strata and surfacing graded spoil with it may greatly improve the chances of revegetation.

3. Minespoil preparation and treatment

If sandstone can be retrieved in the mining process, how much is needed and to what extent does it need to be crushed to serve as surface material? To what extent should topsoil and spoil be incorporated to obtain a suitable interface for moisture and root penetration? Where sodic spoil is encountered, should gypsum be used to enhance water movement into sodic spoil and reduce the problem of upward movement of sodium, and what rates of gypsum are needed?

4. Planting and planting materials

What is the best way to establish warm and cool season species in a stand? In arid climates (<20 cm rainfall) where irrigation is necessary for revegetation, what is the optimum seeding rate? How can the various species be seeded at different depths (e.g. Sporobolus sp at 5mm, Agropyron sp at 2.5 cm and Indian ricegrass at 5.0 cm)?

5. Reclamation planning

6. Hydrology

7. Wildlife and fishery habitat management

IDENTIFICATION OF TECHNOLOGY GAPS AND RESEARCH NEEDS FOR WESTERN MINED-LAND REHABILITATION RESEARCH BY FOREST SERVICE WESTERN REGIONS

James J. Butler[1]

GENERAL

Forest Service Western Regions generally believe there are considerable research findings already available that are not being applied. There is a reluctance on the part of the resource manager to apply research findings to ongoing or planned mined-land rehabilitation because the site and situation may be different than found in the study.

Most research does not provide parameters that can be used in applying results. In some cases this is the result of the limited scope of research. In others it points out the need to broaden the research so that findings can be applied to more sites and situations.

National Forest personnel believe that research study plans do not have sufficient direction built into them for transfer of the findings to the ultimate user in the field. Where research results are applicable to field use, the involved researcher must be trained to disseminate his findings as the ultimate justification of research is application at the field level.

TOPICAL COMMENTS

Reclamation Planning

Research is needed in this area according to Regional responses. It is felt there is a real need to incorporate reclamation planning in the beginning stages of a mining operation based on research and past experience in the area. More "front" end planning is needed rather than leave reclamation to the operating plan stage. While this is in the area of applied research, Forest personnel lack knowledge of how to incorporate research findings early on. Help is needed to develop standards and guides for reclamation planning.

Spoils Placement and Grading

The development and use of large earth moving equipment has led to moving large amounts of over-burden covering deep seated or finely diseminated minerals.

There is a distinct need for research on how to place, retain, and grade, for future reclamation, large over-burden dumps. This is especially true on highly disected and steep mountainous terrain found on National Forests.

What factors do administrators need to consider when approving an area of National Forest for placement of a large dump? How can hazards from dump sites be balanced with efficiency and cost of placement by the producer? How can dump placement and shaping fit better into future uses for the area?

Mine Spoil Preparation and Treatment

Additional research is needed to assure the resource managers that mine spoil preparation and treatment will provide for a lasting useable vegetative cover that can maintain itself under planned future use.

Hydrology

Major technology gaps and research needs exist concerning hydrologic rehabilitation of surface and underground mines and ground water hydrology of large mine dumps.

Research is suggested for a set of predictive process orientated surface hydrologic models that mimic hydrologic processes in three areas:

1. Runoff control--The role of vegetation and structural land and channel treatments in modifying infiltration and surface runoff concentration.

2. Erosion Control--The role of revegetation and structural land and channel treatments in reducing soil detachment by rain splash impact and soil transport by sheet and concentrated runoff.

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[1] Butler, James J. 1982. Special Assistant to Deputy Regional Forester, State and Private Forestry for Energy Development and Mined-Land Rehabilitation, Intermountain Region, USDA Forest Service, Ogden, Utah, 84401.

3. Water Quality Control--The exchange of ions (especially hydrogen and heavy metals) between earth materials and water, and the influence of biological, physical and chemical land treatment on reducing acid and heavy metal pollution.

Given different methods of dump construction and various sizes and levels of dump materials on varying slopes and strata, what ground water patterns will form? How can future dump stability problem be avoided from the development of unanticipated ground water accumulation?

Post Reclamation Site Management

To date, little definitive research has been pursued towards integrating large or small surface mines and their resulting dumps into plans of use for surrounding areas.

How is the management limitation (degree of use) determined?

Specific Mining Type-Uranium

Research on uranium spoils and tailings needs expansion in these areas of concern:

1. Extent of radon gas emission from spoils.

2. Extent that vegetation absorbs uranium from spoils and/or reclaimed tailings.

3. Need for baseline data in form of Iso-rad maps of uranium producing areas to indicate ground radiation and possible long-term effects on wildlife and other users.

MINED LAND RECLAMATION IN THE POWDER RIVER BASIN - PERSPECTIVE OF A WILDLIFE BIOLOGIST[1]

Dean E. Biggins[2]

INTRODUCTION

The vision of a second Appalachia produced by a coal boom on the Northern Great Plains has subsided. In reality, the pace has been somewhat slower than expected, and reclamation vastly more successful than at least a few of the more pessimistic oracles predicted. Coal development has expanded most rapidly in the Powder River Basin of northeastern Wyoming and southeastern Montana, where there are now 20 or so mines. Mines which have reached the reclamation stage are demonstrating that topsoil can be stabilized and that plant communities with good production (of biomass) can be established. Nevertheless, most wildlife biologists depart tours of such reclamation with the disturbing feeling that everything is just too uniform. The topography is usually gentle, there is often only one vegetation type (grassland) and the variety of plant species within it is less than that of native grasslands. The contrast may be striking where the surrounding countryside has variable physiography and a mosaic of plant communities. Why has reclamation taken this course? Reasons vary from legality to expediency, and the philosophical discussion which can develop around this topic is well beyond the intended scope of this paper. However, one cause which we researchers can readily identify and help correct is lack of technology. Practical methods are not available for establishing even some of the most conspicuous and dominant native plants, not to mention a host of lesser species.

SOME PROBLEMS

If there is one key word to sum up the problem it is diversity. Wildlife diversity (and sometimes abundance) is closely linked to vegetational diversity. The plant groups which have presented the greatest problems are trees, shrubs, and forbs. Important limiting factors are moisture and/or seed source.

Availability of moisture is probably the prime concern to both the experimental and operational reclamationist. Weather is an unpredictable provider, and waiting for nature to present the optimum sequence can be frustrating. Thus, supplemental irrigation has been experimentally used on both shrubs (e.g. Orr 1977) and grasslands (e.g. Young 1982). Results have been mixed, but the technique shows promise. Intensive horticultural methods (such as supplemental irrigation) should not be used to establish vegetation where there is little likelihood of development into a self-sustaining community.

More attention needs to be given to identification of microsite/plant relationships. Stark (1982) presented a good example of a systematic approach to identification of site relationships to ponderosa pine (*Pinus ponderosa*), including soil and rock associations. She considered rocks essential to establishment of pine on reclaimed land at Colstrip, Montana. In an experiment near Decker, Montana, containerized gooseberry (*Ribes cereum*) and skunkbush sumac (*Rhus trilobata*) plantings survived 2 to 3 times better near rocks than away from them[3]. In both of these examples, enhanced moisture availability was probably created by the rocks, but the exact mechanisms remain somewhat hypothetical. In the Colstrip study, flat, dark-colored rocks were thought to act as heat pumps, drawing water vapor upward and re-precipitating it directly beneath the rocks. At Decker, the rocks may have afforded wind protection, direct shading, mulch effect, and snowdrift accumulation, all of which tend to either increase moisture availability or decrease moisture loss from transpiration. The point of these examples is to stress the importance of providing a variety of microsites and attendant microclimates. To anthropomorphize from a plant's point of view, the seedling is "thinking" of its prime habitat in terms of square centimeters, while we biologists are often preoccupied with hectares.

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[1] Paper presented at the Western Mined-land Rehabilitation Research Workshop, Fort Collins, Colorado, June 10-11, 1982.

[2] Dean E. Biggins is Wildlife Research Biologist, U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Sheridan, Wyoming 82801.

[3] Biggins, Dean E., Dale B. Johnson and Michael R. Jackson. Effects of rock structures and condensation traps on shrub establishment. Manuscript in preparation.

Even if prescriptions are developed for providing optimum microsite (and macrosite) diversity, seed source may be a problem. This is especially true of forbs, with commercial seed available for a relatively small number of native species. Native hay may be broadcast as a mulch and seed source. This technique needs further investigation, but would seem to provide an increase in variety of grasses and some forbs. Directly hauled topsoil from stripped to reclaimed sites has already qualilatively demonstrated its ability to increase species diversity and further quantitative testing is desirable. The concept could be carried one step further by directly respreading the top layer of A_1 soil and accumulated litter, where most seed should be stored. This has not been thoroughly investigated, and should be tested for a number of different plant communities.

With shrubs and trees, other options are available. In fact direct seeding of shrubs has been only "partially successful" (Clark and DePuit 1980), and even then with very few genera (e.g. *Eurotia* and *Atriplex*). Transplanting is an attractive alternative. It may prove too labor intensive to be practical for direct establishment of large shrub stands, but can certainly provide a source for both seed and vegetative reproduction.

RESEARCH NEEDS

I have addressed in the previous discussion what I believe are a few of the most significant areas of concern. The list which follows identifies some research topics within the foregoing areas, as well as introducing a few new subjects.

1. Investigate effects of artificial rock "outcrops" on survival of trees and shrubs. Research should include identification of best types and sizes of rock, placement strategies, groupings, and evaluation of prime microsite conditions in and around rock structures for each species.

2. Evaluate possibilities of using spot treatments of "poor" quality topsoils (e.g. rocky or sandy) as planting media. These soils may be more suitable for some species of plants because of reduced competition and numerous other factors.

3. Compare use of various mulches (e.g. crushed scoria rock, polyethylene, hydromulch, straw, etc. to enhance survival of transplants during years of adverse weather.

4. Experiment with drip irrigators as above.

5. Conduct further investigations on effects of surface relief modifications (e.g. gouging, mounding, terracing) on plant establishment.

6. Compare species diversities of plant communities established with direct topsoil placement (AB horizons) and direct A_1 horizon and duff replacement; evaluate preceding when used in conjunction with overseeding of normal seed mixes.

7. Compare growth and survival of local plant ecotypes and those from distant sources.

8. Develop and/or test animal repellant chemicals or devices for protecting seedings and plantings from herbivore damage (e.g. Vexar tubes - Crouch 1980).

9. Test root sprigging (Jensen and Hodder 1979) as a technique to establish woody draw vegetation.

10. Test sodding as technique to establish seed producing "islands" of certain species of grasses and forbs.

11. Compare efficiencies of transplanting using various types of planting stock (i.e. bare root, containerized, and direct transplants).

The foregoing discussion and list is obviously not an exhaustive treatise on all of the variables and problems involved with rehabilitation of mined lands. It is a perception of useful research based on my field experience with wildlife/mining associations, and to no small degree on my own association with reclamationists.

THE SHERIDAN FIELD STATION, DWRC

The Sheridan Field Station of the Denver Wildlife Research Center was established in 1975 to investigate effects of strip mining on wildlife. Initial involvement with experimental reclamation began on a small scale in 1978. Discussions concerning methods to increase plant diversity were initiated with reclamationists at Decker Coal Company, Decker, Montana, and the Montana Department of State Lands later approved a test site on an overburden storage area. First experiments were designed to assess the effects of rock structures on survival of locally common shrubs. Some preliminary findings were mentioned earlier. More recent experiments have involved testing of mulches and topsoiling techniques. Initial success with the rock experiments has led to adoption of this technique in permanent reclamation activities at the East Decker Mine. Decker Coal Company should be commended for its progressive attitude, and we appreciate their close cooperation with these and other studies.

CONCLUDING REMARKS

Our early experiences with development of new reclamation techniques have been rewarding, and illustrate the possibilities of positive interaction between industry and government. Presentations at recent symposia demonstrate that good progress is being made by industry and public agencies, and the face of reclamation seems to be changing. Our desire, indeed our responsibility as researchers, is to provide the reclamationist with as many practical and cost effective tools as possible so that meaningful choices can be made - instead of "choice" by default. Diverse wildlife habitat may not always be the primary goal, but we will have done our part toward making it a viable option.

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Colorado State University Agronomy Department

DISTURBED LANDS RESEARCH

B. R. Sabey

A. Organization's Mission

Our mission is to supply technical and practical information through research to assist managers of disturbed lands in successfully reclaiming those areas as effectively and economically as possible. We additionally desire to provide information to regulatory agencies to assist them in developing practical, meaningful, and feasible reclamation regulations that protect our environment and promote effective use and stewardship of our natural resources.

B. Accomplishments - Past 10 years

1. Anvil Points - Tosco and USBM Retorted Shale - EPA

a. Experimental Plots Set-Up

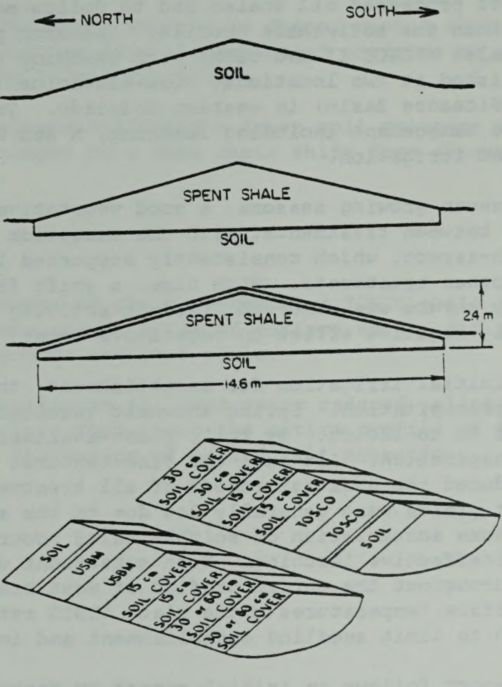

Figure 1. Diagram of the low- and high-elevation study treatments.

Each research site contains a set of 3.3 m x 6.6 m plots with the following treatments:

1. Leached TOSCO retorted shale
2. Leached TOSCO retorted shale with 15-cm soil cover
3. Unleached TOSCO retorted shale with 30-cm soil cover
4. Leached USBM retorted shale
5. Leached USBM retorted shale with 15-cm soil cover
6. Unleached USBM retorted shale with 30-cm soil cover at the high-elevation site or 60-cm soil cover at the low-elevation site
7. Soil control

Each of the seven replicated treatments had a north and a south exposure on a 4:1 (25%) slope. A diagram of the treatment arrangement at each site is shown in Figure 1.

b. Abstract

Field studies were initiated in 1973 to investigate the vegetative stabilization of processed oil shales and to follow moisture and soluble salt movement within the soil/shale profile. Research plots with two types of retorted shales (TOSCO II and USBM) with leaching and soil cover treatments were established at two locations: low-elevation (Anvil Points) and high-elevation (Piceance Basin) in western Colorado. Vegetation was established by intensive management including leaching, N and P fertilization, seeding, mulching, and irrigation.

After seven growing seasons, a good vegetative cover remained with few differences between treatments, with the exception of the TOSCO retorted shale, south-aspect, which consistently supported less perennial vegetative cover than other treatments. With time, a shift from perennial grasses to dominance by shrubs was observed. Rodent activity on some treatments had a significantly negative effect on vegetative cover.

After initial irrigation for establishment, the vegetation was dependent on seasonal precipitation. Spring snowmelt resulted in recharge of profiles to depths of 60 to 120 cm. By fall, plant-available moisture was depleted by evapotranspiration. Although the fine-textured TOSCO retorted shale usually produced the greatest runoff of all treatments, the surface runoff and sediment yields were generally low due to the adequate vegetative cover. Initially, some accumulation of soluble salts occurred at the surface because of ineffective leaching. With subsequent weathering, salinity decreases throughout the entire profile of most treatments were observed. Recorded surface temperatures of the black TOSCO retorted shale were sufficiently high to limit seedling establishment and increase surface evaporation.

This report follows an initial report by Harbert and Berg (1978) which detailed the construction, establishment techniques, and interpretation of measurements from 1973 to 1976.

c. Conclusions

LOW-ELEVATION STUDY SITE

Vegetation

1. After seven growing seasons, a good vegetative cover (52% to 68%) existed on all treatments.
2. The TOSCO retorted shale, with no soil cover, generally supported less perennial vegetation throughout the years, than other treatments.
3. A shift in vegetative composition from perennial grasses to predominance by xeric shrubs occurred on all treatments.

Moisture

1. With average seasonal precipitation most treatment profiles were recharged to levels of 20% to 25% moisture by volume in the spring to depths of 60-120 cm.
2. Good vegetative cover, especially deeper-rooted shrubs, extracted substantial moisture from all treatment profiles to approximately 10% moisture by volume by fall.
3. South-facing slopes reflected a drier soil moisture regime than north-facing slopes by a more rapid shift from grasses to xeric shrubs.

Salinity

1. Leached treatments of the fine-textured TOSCO shale initially experienced some accumulation of surface salts, and salinization of soil covers over retorted shale.
2. Seasonal precipitation in later years reduced salinity levels to 5 mmhos/cm or less throughout the entire profile of leached treatments with no indication of upward salt migration.

Runoff and Water Quality

1. The quantity and quality of spring snowmelt runoff depended on whether the ground surface was frozen or thawed.
2. A greater runoff volume resulted when the ground surface was frozen, and was of high water quality.
3. Small amounts of runoff in 1978 were rated medium to very high salinity hazard (1210 - 3200 µmhos/cm).
4. The use of a mulch during vegetative establishment and the present vegetative cover contributed to low sediment yields for all treatments.

Surface Temperatures

1. Maximum temperatures of 60-65 C at a 1 cm depth were recorded in mid-summer on TOSCO south-facing plots. Temperatures from south-facing soil plots were about 5 C lower.
2. On north-facing TOSCO shale plots temperatures at 1 cm depth were approximately 50 C, compared to 30 C for north-facing soil plots.

HIGH-ELEVATION STUDY SITE

Vegetation

1. The initial vegetation established in 1974 was unsatisfactory because: perennial grasses were seeded at a low rate, a too dense stand of big sagebrush resulted, and the inadequately leached retorted shales were resalinized.
2. After releaching, rototilling, and reseeding a good stand resulted.
3. Rodent activity, particularly pocket gophers, caused considerable surface disturbance resulting in a loss of vegetative cover.
4. A shift from perennial grasses to predominance by xeric shrubs was observed.

Moisture

1. Spring snowmelt resulted in recharge of profiles to depths of 60-120 cm.
2. Evapotranspiration resulted in depletion of plant-available moisture in the profiles by fall.

Salinity

1. Due to high evaporative demand and low irrigation rates, resalinization of the leached layer over the retorted shales resulted in 1974.

2. Resalinization did not occur after the 1975 releaching.

3. Seasonal precipitation and continued weathering reduced soluble salts to 5 mmhos/cm or less throughout the entire profile of leached treatments by 1980, with no indication of upward salt movement.

Runoff and Water Quality

1. Spring snowmelt was responsible for the majority of surface runoff on all treatments.

2. When small amounts of runoff resulted, from either limited snowmelt or summer thunderstorms, the salinity hazard was rated high to very high from the retorted shales (1120 - 7200 umhos/cm).

3. The sodium hazard and sediment yields were rated low for runoff from all treatments.

d. Recommendations

1. Intensive management will be required to establish a satisfactory vegetative cover within a reasonable amount of time.

2. As a specific retorting method develops, investigation of the waste as a plant growth media requires a thorough examination of the physical and and chemical characteristics of the retorted shale.

3. The eventual erosion of soil cover or modified retorted shale, particularly from steep south-facing slopes, could result in continued exposure of less weathered retorted shale. This should be considered in future waste stabilization research and planning.

4. The ultimate fate of applied leach water, along with a comprehensive water balance (especially for high-elevation disposal sites) should be addressed.

5. Large herbivores were restricted from the small plots in this study by fencing, future research should evaluate both wildlife and domestic livestock use on the retorted shale disposal site.

6. The retorted shale disposal site stabilization plan must allow for localized severe rodent disturbances as observed in this study.

2. Anvil Points Lysimeter Study - Paraho Retorted Shale - EPA

a. Experimental Plot Set-up

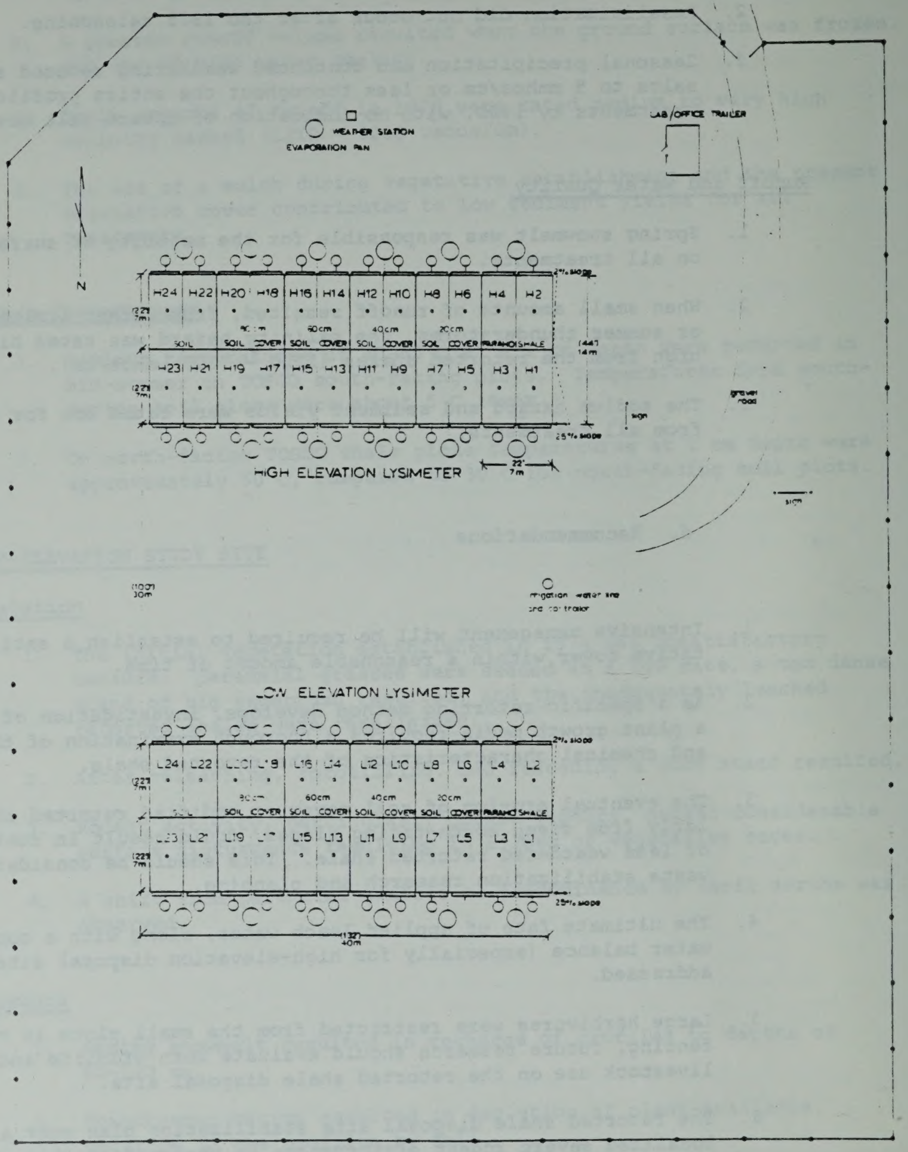

Figure 2. Diagram of the Paraho retorted shale lysimeter study treatments.

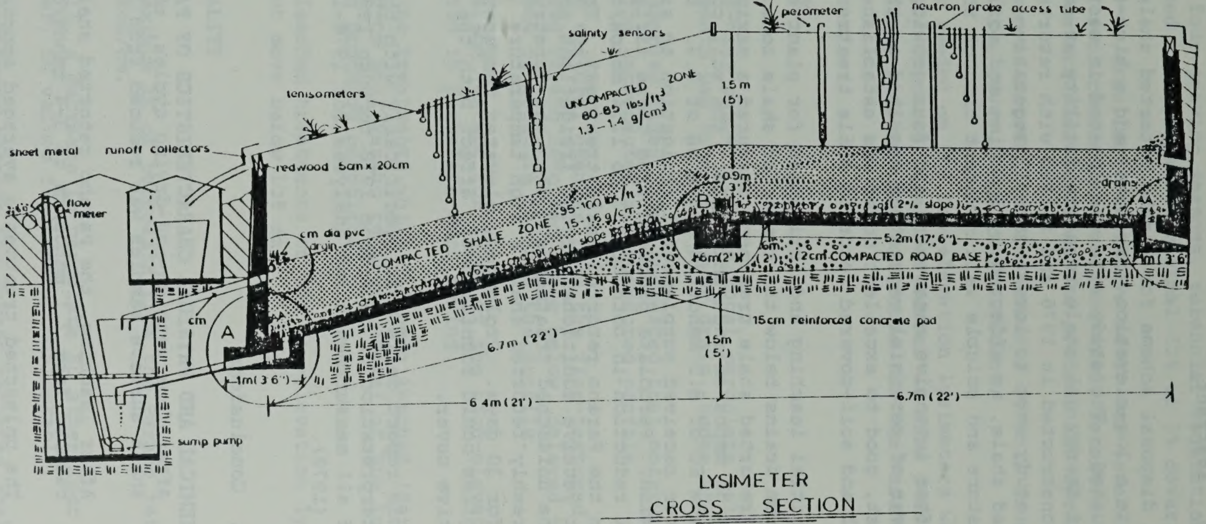

Figure 3. Cross section of the lysimeter design.

b. Abstract

A disposal scheme for Paraho retorted shale utilizing lysimeters to simulate a low-elevation (dry site) and a high-elevation (moist site) was constructed. The study site was located in western Colorado at the Department of Energy oil shale research facility at Anvil Points. The lysimeters were constructed in 1976 and filled with retorted shale in 1977. Objectives of the study were to investigate 1) vegetative stabilization of Paraho retorted shale, as affected by leaching and soil cover treatments; and 2) moisture and soluble salt movement through the soil/shale profile.

After intensive management and four growing seasons, only a sparse (2% to 3%) cover of perennial vegetation resulted on the Paraho retorted shale. In contrast, good to excellent cover was established and maintained on the soil control and soil-covered retorted shale treatments.

Initial leaching and irrigation for plant establishment produced percolate from drains below the compacted shale zone. The percolate from the Paraho retorted shale treatment measured a maximum electrical conductivity (EC) of 35 mmhos/cm and a pH of 11.4. The soil control produced percolate with a maximum EC of 8.5 mmhos/cm and a pH of 8.3. Each spring the high-elevation lysimeter received supplemental irrigation to simulate a zone of higher precipitation. Percolate produced from these irrigations exhibited a general overall reduction in both EC (33 to 11.4 mmhos/cm) and pH (11.4 to 8.6) by 1980 on the Paraho retorted shale treatment. The low-elevation lysimeters did not receive additional spring irrigations and no percolate was produced from the unleached treatments. When the constructed lysimeters were filled with freshly retorted shale a high temperature (60 C) was maintained at a 1 m depth for 30 days. Prolonged, elevated temperatures of retorted shale disposal piles could significantly affect both the amount and composition of vegetative cover.

This report deals most specifically with the collection, measurement, and interpretation of data from 1978 through 1980. A more detailed description of all measurements and analyses for 1976-1977 was reported in Harbert et al. (1979).

c. Conclusions

CHEMICAL AND PHYSICAL CHARACTERISTICS OF PARAHO RETORTED SHALE

1. After four wetting-and-drying cycles, the pH of Paraho retorted shale surface samples was reduced from 11.2 to 9.0.

2. After leaching, the Paraho retorted shale soluble salt content was reduced from 7.1 mmhos/cm to 3-4 mmhos/cm.

3. The unleached treatments averaged approximately 10 mmhos/cm throughout the retorted shale profile, although, there was no indication of upward migration of soluble salts by 1979.

4. Laboratory analyses of 1977 core samples suggested that imbalances of calcium, magnesium, and sodium might inhibit plant growth on the Paraho retorted shale.

5. Surface temperatures reached 80 C on south slopes of the black-colored Paraho retorted shale. This might be lethal to seedlings, while increasing surface evaporation.

VEGETATION

1. After four growing seasons, perennial vegetation on the Paraho retorted shale remained minimal (2% to 3% cover).

2. A good to excellent vegetative cover was established and maintained on the soil control and soil-covered, retorted shale treatments, with western wheatgrass as the predominant species.

3. Differences between varying amounts of soil cover, with respect to vegetative cover, were insignificant.

4. Shrubs seeded on the low-elevation lysimeters were unable to significantly increase in either number or size over four growing seasons, indicating limited root tolerance for the Paraho retorted shale.

PERCOLATE

1. Ninety-nine percent of the total percolate collected from all treatments was from the lower drain, under the compacted zone.

2. Core samples taken later suggested that moisture had moved through both the uncompacted and compacted profile.

3. Abrupt textural changes from the fine-textured soil to the coarse-textured Paraho retorted shale below, delayed the uniform downward movement of moisture through the profile.

4. Irrigation (except for 1980) of the high-elevation lysimeters resulted in percolate each spring.

5. Only the treatments which had been leached (Paraho retorted shale and 20-cm soil/Paraho retorted shale) of the low-elevation lysimeters produced percolate.

6. On unleached treatments of the low-elevation lysimeters moisture did not move below 105 cm.

WATER QUALITY

1. The maximum EC of percolate from the Paraho retorted shale was 35 mmhos/cm.

2. Overall, a decrease in percolate EC after four years was observed, however, EC values fluctuated considerably.

3. If water moves through the Paraho retorted shale a high pollution potential exists, with respect to EC and SAR values measured.

4. Greater total pore volumes must pass through the lysimeters before the chemical composition of the percolate stabilizes.

DISPOSAL PILE TEMPERATURES

1. The freshly retorted shale used in this study maintained 60 C temperatures for 30 days.
2. Prolonged, elevated temperatures could significantly affect both the amount and composition of vegetative cover on disposal piles.

d. Recommendations

1. Because of the unsuitability of the Paraho retorted shale as a direct plant growth media, soil cover is recommended for successful establishment of vegetation on the retorted shale.
2. Poor establishment and growth of the fourwing saltbush suggested limite root penetration into the Paraho retorted shale. Additional studies ar needed to evaluate root growth in retorted shale.
3. Efforts should be made to prevent movement of water through the retorte shale as leach water poses a pollution potential due to high soluble sa content.
4. Research is needed to insure that the compacted shale can be made impervious, since in this study, moisture moved through Paraho retorted shale compacted to a density of 1.5 to 1.6 g/cm^3.
5. Elevated temperatures maintained in the retorted shale disposal pile might adversely affect the establishment of vegetation. Further investigation under commercial disposal pile conditions is recommended.
6. The present fluctuations in chemical composition of leachate from the lysimeters require that additional pore volumes of water are needed to evaluate leachate quality.

3. Parachute Creek Valley Plots - Union Decarbonized and Union B Retorted Shale

a. Experimental Plot Set-up

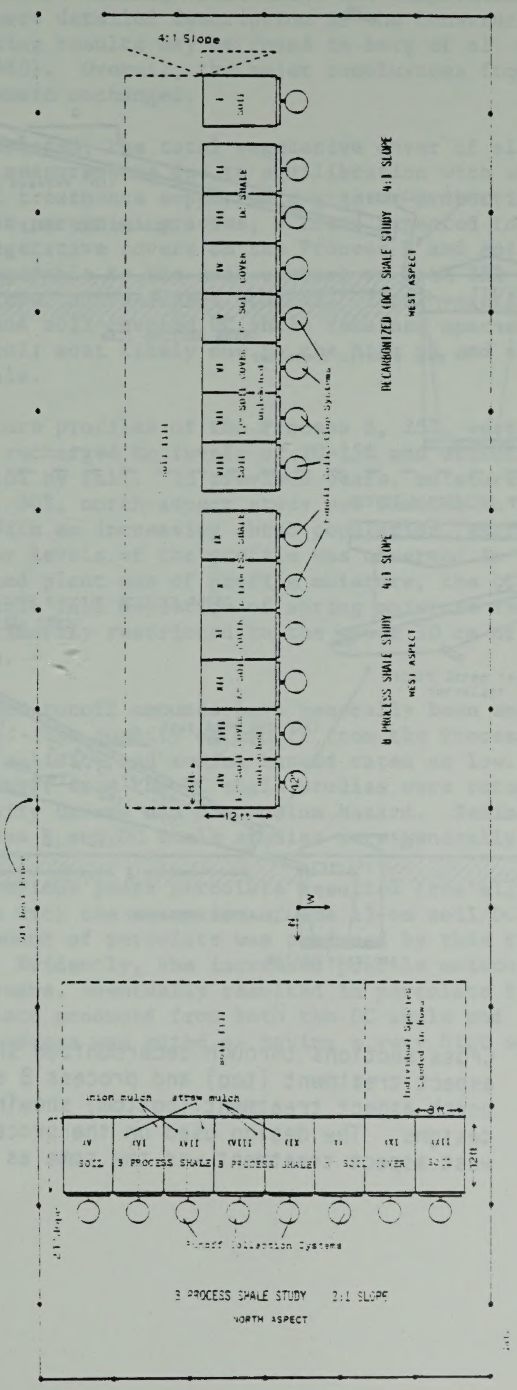
4:1 Slope
Soil fill
8ft
12ft
I SOIL
II III DC SHALE
IV V 6" SOIL COVER
VI VII 12" SOIL COVER unleached
VIII SOIL
IX X B PROCESS SHALE
XI XII 6" SOIL COVER
XIII XIV 12" SOIL COVER unleached
42"
Runoff Collection Systems
DECARBONIZED (DC) SHALE STUDY 4:1 SLOPE
WEST ASPECT
B PROCESS SHALE STUDY 4:1 SLOPE
WEST ASPECT
N
W
Soil fill
Individual Species Seeded in Rows
8ft
union mulch
straw mulch
IV SOIL
XVI XVII B PROCESS SHALE
XVIII XIX B PROCESS SHALE
XX 6" SOIL COVER
XXI XXII SOIL
12ft
2:1 Slope
Runoff Collection Systems
B PROCESS SHALE STUDY 2:1 SLOPE
NORTH ASPECT

Figure 4. Plot plan for Union Oil Company valley vegetative stabilization research study. Decarbonized shale 4:1, west aspect study constructed June 1974. Process B 4:1 slope, west aspect study and 2:1 slope, north aspect study both constructed June 1975.

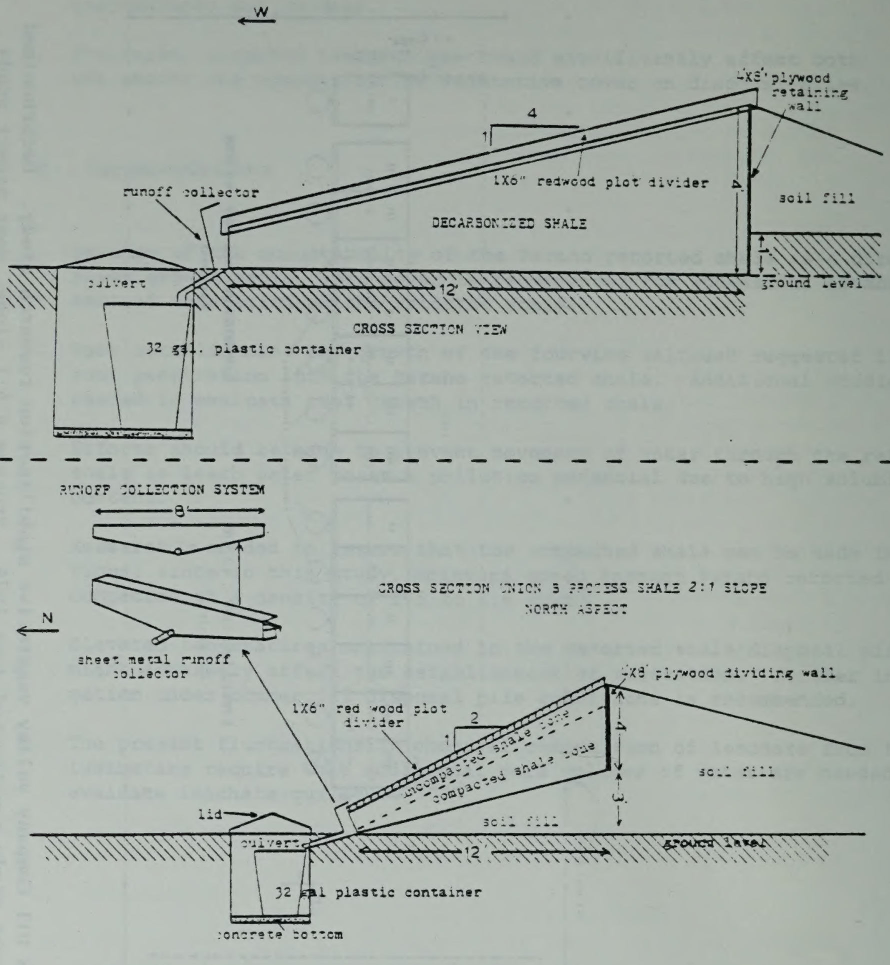

Figure 5. Cross sections through decarbonized shale 4:1 slope, west aspect treatment (top) and process B shale 2:1 slope, north aspect treatment (bottom) showing construction designs. The design used on the process B 4:1 slope, west aspect treatment was the same as the DC shale design.

b. Abstract

This report deals primarily with the collection and interpretation of 1979 and 1980 field data from Union Oil Company retorted oil shale studies. Although references and comparisons are made to previous years, a more detailed description of the construction, establishment, and preceding results may be found in Berg et al. (1979) and Herron et al. (1980). Overall, the major conclusions from the previous reports remain unchanged.

As expected, the total vegetative cover of all treatments decreased from 1978 measurements due to equilibration with seasonal precipitation. Almost all treatments supported a greater proportion of cover as shrubs rather than perennial grasses, a trend expected to continue in future years. Vegetative covers on the Process B and soil-covered process B were comparable to the soil control on both 25% slope, west-aspect and 50% slope, north-aspect studies. Total vegetative cover on the DC shale and soil-covered DC shale remained sparse compared to the soil control; most likely due to the high pH and cementing action of the DC shale.

Moisture profiles of the Process B, 25%, west-aspect study were generally recharged to levels of 20-25% and depleted by evapotranspiration to about 10% by fall. In previous years, moisture use by plants on the Process B, 50%, north-aspect study was limited to the upper profile levels. With an increasing shrub population, extraction of moisture from deeper levels of the profile was observed in 1979 and 1980. With limited plant use of profile moisture, the DC shale treatments showed little fall depletion of spring moisture recharge. Moisture use was primarily restricted to the upper 30 cm of the profile in these treatments.

Surface runoff amounts have generally been small from most treatments. The quality of runoff from the Process B studies was good, with both salinity and sodium hazard rated as low. Small amounts of surface runoff from the DC shale studies were rated as low to medium-high salinity hazard and low sodium hazard. Sediment yields from both Process B and DC shale studies were generally considered low.

In previous years percolate resulted from all DC shale lysimeter treatments with the exception of the 15-cm soil/DC shale lysimeter. A small amount of percolate was produced by this treatment in 1979 and 1980. Evidently, the increased profile moisture measured in previous years, eventually resulted in percolate from this lysimeter. The percolate produced from both the DC shale and 15-cm soil/DC shale lysimeters was rated as having a very high sodium and salinity hazard.

4. Parachute Creek Steep Slope Study - Union B Retorted Shale

a. Experimental Plot Set-up

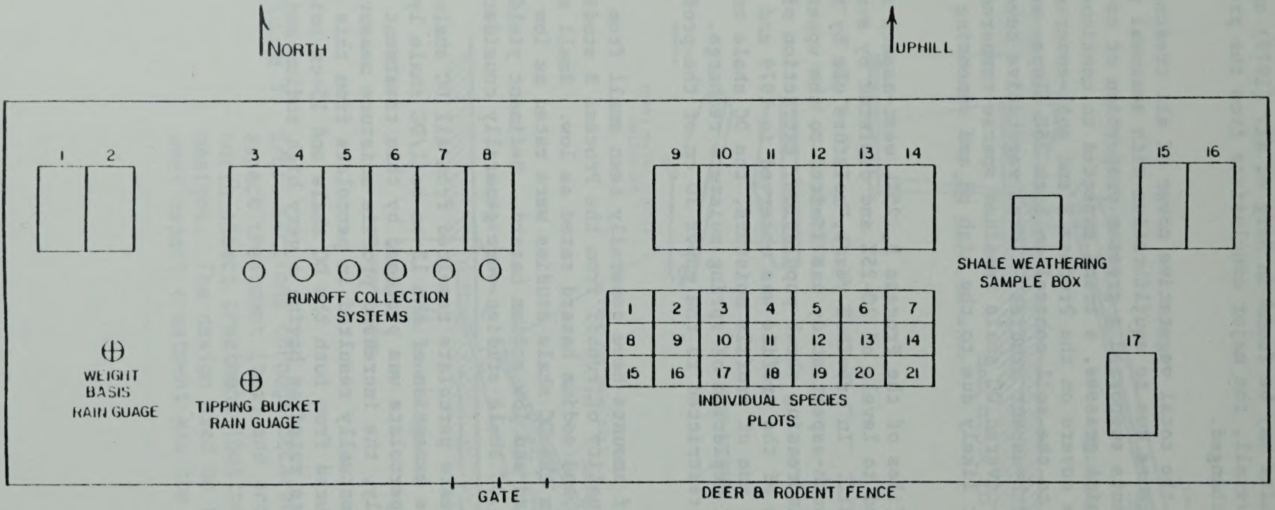

Figure 6. Site layout - Union Oil Company vegetative stabilization research site. 57% south-aspect study (plots 3-8), barley cover/companion crop study (plots 1, 2, 9-14) constructed June 1979, plots 15-17 constructed October 1979.

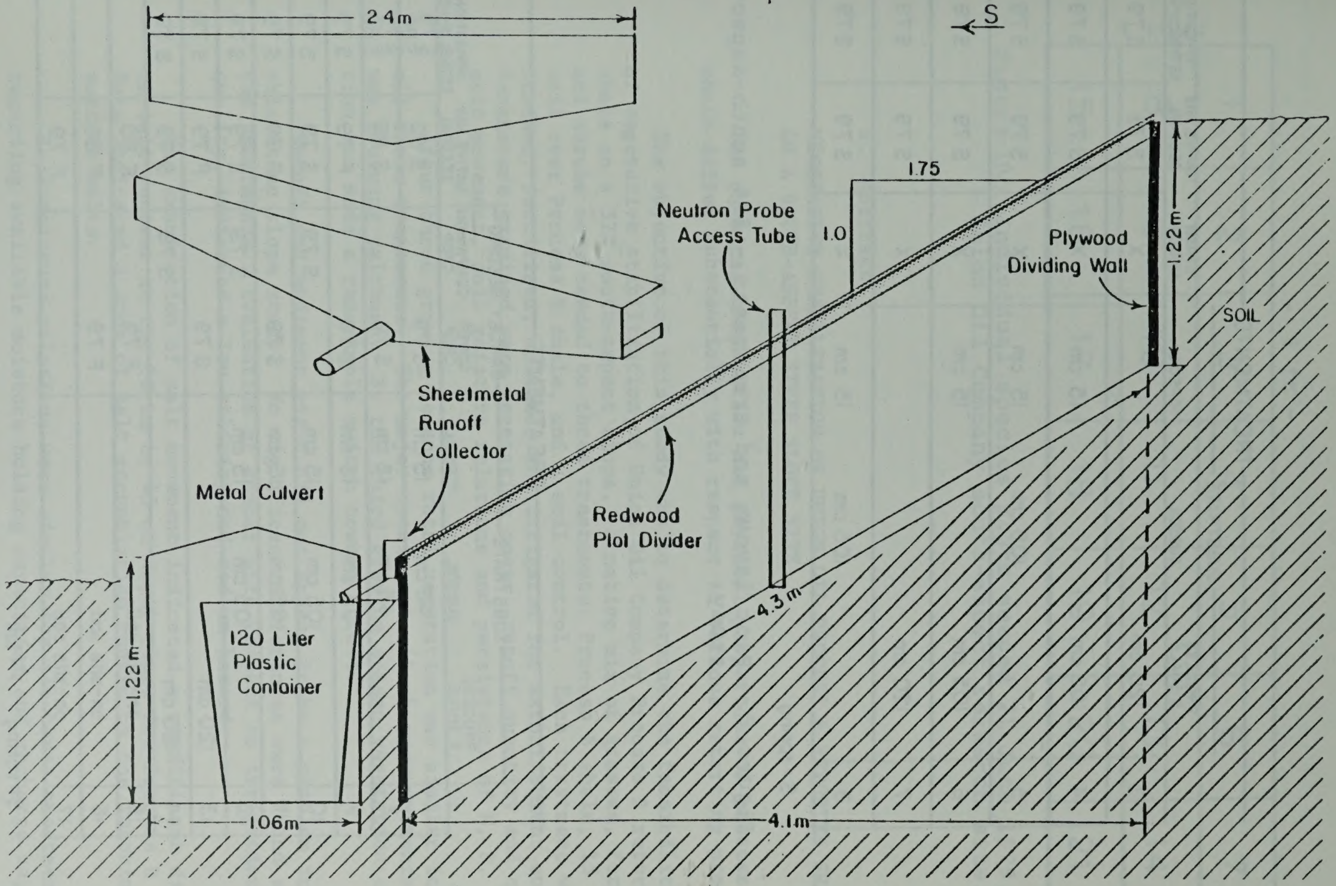

Figure 7. Cross-section through 57% south-aspect plots showing construction and design, June 1979.

	TREATMENTS					
	SUBSTRATE					
	PROCESS B SHALE	SUBSOIL	TOPSOIL	STRAW MULCH	NATIVE MIX SEEDING	IRRIGATION ESTABLISHMENT
3	120 cm			X	S 79	S 79
4	105 cm		15 cm	X	S 79	S 79
5		105 cm	15 cm	X	S 79	S 79
6	105 cm		15 cm	X	S 79	S 79
7	120 cm			X	S 79	S 79
8		105 cm	15 cm	X	S 79	S 79

S = spring

Figure 8. Plot layout and treatments - 57% south-aspect study.

	TREATMENTS						
	SUBSTRATE			BARLEY SEEDING			
	PROCESS B SHALE	SUBSOIL	TOPSOIL	COVER CROP	COMPANION CROP	NATIVE MIX SEEDING	IRRIGATION ESTABLISHMENT
1		45 cm	15 cm	S 79		S 80	S 79 S 80
2		45 cm	15 cm	S 79		S 80	S 79 S 80
9		105 cm	15 cm	S 79		F 79	S 79
10		105 cm	15 cm		S 79	S 79	S 79
11		105 cm	15 cm	S 79		F 79	S 79
12		105 cm	15 cm		S 79	S 79	S 79
13	120 cm			S 79		F 79	S 79
14	120 cm				S 79	S 79	S 79
15	on-site soil			F 79		F 80	
16	on-site soil			F 79		F 80	
17	on-site soil					F 79	

S = spring F = fall

Figure 9. Plot layout and treatments - barley cover/ companion crop study.

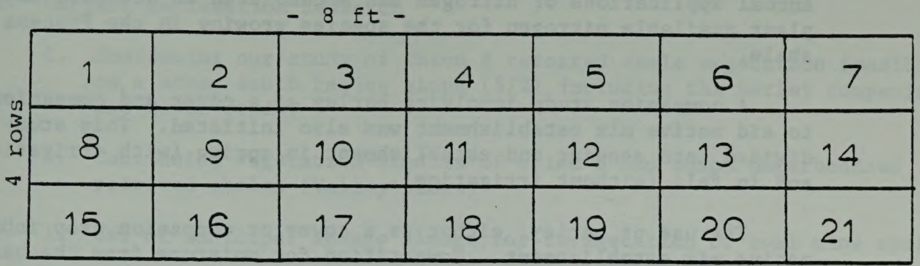

Figure 10. Individual species plots seeded 21 June 1979. Union Oil Company south-aspect research site.

b. Abstract

VEGETATIVE STABILIZATION OF UNION OIL PROCESS B RETORTED SHALE ON A SOUTH-ASPECT STEEP SLOPE SITE

The chemical composition and physical properties of process oil shale differ substantially with respect to various retorting processes.

The objective of this study was to determine the feasibility of vegetative stabilization of Union Oil Company Process B retorted shale on a 57% south-aspect slope. A native mix of grasses, forbs, and shrubs were seeded to three treatments: Process B shale, 15 cm soil over Process B shale, and a soil control. Each treatment was leached, fertilized, mulched, and irrigated for establishment only. Parameters examined were vegetation cover, runoff quantity and quality, salt movement, soil moisture relations and persistence of N, P, and K.

After three growing seasons total vegetation was similar for all three treatments. The major species on all three treatments was fourwing saltbush. By the third growing season vegetation composition had made a remarkable switch toward shrubs.

Runoff and sediment yield did not appear to be a problem in this steep slope study. No significant differences were found among the treatments. Evaluation of runoff with respect to irrigation water quality, indicated a low salinity and sodium hazard.

The examination of salt movement indicated a significant difference in salt content at the 30 cm to 45 cm depth range for Process B shale. Data indicated a zone of salt accumulation caused by the leaching of surface salts.

Soil moisture relations were similar for all three treatments regarding available moisture holding capacities and recharge capabilities.

Natural amounts of available potassium in processed B shale were found to be adequate for long-term needs. Available phosphorus had been depleted over three growing seasons since its initial application.

Annual applications of nitrogen had accumulated an adequate amount of plant available nitrogen for the species growing in the Process B shale.

A companion study involving barley as a cover and companion crop to aid native mix establishment was also initiated. This study was divided into seeding and establishment in spring (with irrigation) and in fall (without irrigation).

The use of barley, either as a cover or companion crop inhibited native mix establishment. Competition for moisture from the barley companion crop even with irrigation appeared to be detrimental to native mix establishment. Those barley cover crop treatments in which the native mix was not irrigated established little or no perennial cover.

C. Current Reclamation Research

1. Continuing our study of Union B retorted shale vegetation feasibility on a steep south facing slope (57%) including the barley companion and cover study.

2. Continuing vegetation studies of Union B and Union Decarbonized retorted shales (Valley plots)

3. Use of municipal sewage sludge for revegetation of coal mine spoils

D. Technology Gaps

The major need in revegetation and stabilization of retorted oil shale is to move from small experimental plots to a field scale study, thus evaluating how the numerous small plot studies predict what will happen under field scale conditions.

1. Reclamation planning

2. Spoil placement and grading

3. Minespoil preparation and treatment
    a. Soil testing and coorelations for nutrient recommendations
    b. Effect of initial irrigation on germination, establishment and subsequent species competition (large field plots)
    c. Effect of fertilizer application on species competition on large field plots
    d. Effect of high C/N mulches on nitrogen need and supply to plants
    e. Compaction studies below root levels to prohibit leaching of potential pollutants

4. Planting and planting materials
    a. Development of optimal seed mixes for germination, establishment and subsequent diversity of persistent species.
    b. Evaluation of grass, forb, and shrub, competition and establishment on disturbed lands

5. Hydrology
    a. Evaluation of water movement and salt movement. (Rates of upward and downward movement and factors affecting) in an an attempt to evaluate the pollution potential of salts and other compounds moving into streams or groundwater

6. Wildlife and fishery habitat management

7. Post reclamation site management

    a. Evaluation of the frequency and application rate phosphorus for maintenance of adequate plant biomass, diversity and cover for soil stabilization.

    b. Long term successional studies are needed on field sized areas wherein such parameters as initial irrigation, fertilization, slope % and aspect, and species mix are evaluated.

COAL HYDROLOGY PROGRAM OF THE U.S. GEOLOGICAL SURVEY

by

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Abstract. The Surface Mining Control and Reclamation Act of 1977 (P.L. 95-87) requires coal mining permit applicants to make a determination of the probable hydrologic consequences of their mining and reclamation operations. Furthermore, it states that a permit cannot be issued until:

> "hydrologic information on the
> general area is made available
> from an appropriate Federal or
> State agency."

Recognizing that this requirement would necessitate an expansion of hydrologic data collection and analysis in the coal resource areas of the Nation, the Congress appropriated funds to the U.S. Geological Survey in 1979 to support the hydrologic data and information requirements of the Act. The network established to acquire the needed data includes hundreds of synoptic stream measurement sites and an expansion of water quality and sediment sampling at existing continuous record streamflow stations nationwide. To disseminate this information, the Geological Survey is preparing a series of hydrologic assessment reports appraising the hydrology of selected drainages in the coal areas. These reports contain data on geology, physiography, drainage, land-water use, soils, precipitation, streamflow characteristics, and water quality. In addition, research studies are underway to support data collection and analysis methodologies and to develop techniques to assess the cumulative impacts of mining.

Introduction

The mission of the Water Resources Division of the U.S. Geological Survey is to provide the hydrologic information which is essential for the optimum utilization and management of the Nation's water resources. This mission is accomplished through cooperative programs with other Federal and State agencies. The data provided are necessary for the continuing determination and evaluation of the quantity, quality, and use of the Nation's water resources; the data collected are useful in conducting research in hydraulics, hydrology, and related fields of science thereby improving our understanding of hydrologic systems' response to stress, either natural or manmade.

The Geological Survey has been steadfast in maintaining a position of unbiased data collection and interpretation in order that it could best serve the national interests. In such a role and because of the Survey's hydrologic expertise, it was logical that the Congress authorize $4.8 million in 1979 and an additional $4.1 million in 1980 to the Survey to be used in acquiring and disseminating the hydrologic information collected to support the Surface Mining Control and Reclamation Act of 1977 (SMCRA).[1] This paper is a report on how the U.S. Geological Survey is undertaking to aid the coal mining industry and Federal and State Regulatory Authorities by acquiring, interpreting, and disseminating water data and information characterizing the hydrology of the Nation's coal areas and by developing methods to assess the probable cumulative impacts of anticipated mining.

The Act

The first national effort at controlling coal mining to produce environmentally acceptable operations was undertaken with the enactment of P.L. 95-87, the Surface Mining Control and Reclamation Act of 1977. The Act and the ensuing Regulations are replete with hydrologic requirements either in regard to collecting water resource information or through the measurement of hydrologic factors as a means of assessing impacts.[2] The portion of the Act most influencing the Survey's program has to do with Secton 507 (b)(11). This section states that the permit application shall contain:

> "a determination of the probable hydrologic consequences of the mining and reclamation operations, both on and off the mine site, with respect to the hydrologic regime, quantity and quality of water in surface and ground water systems including the dissolved and suspended solids under seasonal flow conditions and the collection of sufficient data for the mine site and surrounding areas so that an assessment can be made by the regulatory authority of the probable cumulative impacts of all anticipated mining in the area upon the hydrology of the area and particularly upon water availability: Provided, however, that this determination shall not be required until such time as hydrologic information on the general area prior to mining is made available from an appropriate Federal or State agency: . . . ."*

In the Regulations (30 CFR 770.5), it is clear that the intent is to assess the probable cumulative impacts of mining within the general area of the proposed mine site(s); this term being defined with respect to hydrology as:

> "the topographic and ground water basin surrounding a mine plan area which is of sufficient size, including areal extent and depth, to include one or more watersheds containing perennial streams and ground water zones . . . ."

It is important to note that here and elsewhere in the Regulations,** the clear distinction is made that site-specific hydrologic data is the responsibility of the applicant and general area data is the responsibility of a Federal or State agency. The applicant is also given the option of acquiring the data if not available from a Federal or State agency. The exception is for small operators*** for which site data will be acquired by laboratories**** qualified and paid for by the Office of Surface Mining Reclamation and Enforcement (OSM). The Geological Survey is directly concerned with meeting its obligation as described above to characterize the general area hydrology. The Survey is also vitally concerned with developing methods and techniques to determine the probable hydrologic consequences and making assessments of the cumulative impacts of mining.

General Area Hydrology

Program on Federal Lands

Figure 1 shows the six major coal provinces of the United States. Most Federal-owned coal lands are located in the Northern Great Plains and the Rocky Mountain Provinces. A joint program by the Bureau of Land Management (BLM) and the Survey was initiated in these two Provinces in 1975. The objective was to obtain baseline hydrologic data with which to characterize regional hydrologies

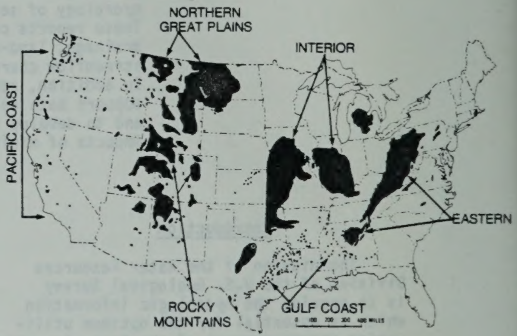

Figure 1. Coal Provinces of the United States (after Trumbill, 1960 and Barnes, 1961).

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*Underlining for emphasis by the authors

**Sections 30 CFR 779.4; 779.13;

***Defined as being one who mines between 250 to 100,000 tons per year.

****To also mean public or private agencies, technical consulting firms, etc.

as well as to assess mining impacts. These data and interpretive reports are being used in Environmental Impact Statements and land use planning as part of the basis for determining what lands are acceptable for leasing and to aid in the environmentally sound management of leases.

The hydrology program for the Federal lands differs somewhat from the more recent program developed for the heavily mined Eastern and Interior Coal Provinces. The differences are due to the more arid climate of the Federal lands in the West, the large size but limited number of mining operations, and the fact that programs were not tailored initially to SMCRA, which did not exist at the time these programs were initiated. The program is designed to evaluate and describe the regional hydrology of large tracts of Federal lands that are proposed for leasing. The scarcity of existing long-term hydrologic data and the difficulty of obtaining new and pertinent data have made the task difficult. To overcome the difficulties and to aid BLM in assessing the regional hydrology, the Energy Mineral Rehabilitation Inventory and Analysis (EMRIA) program has undertaken the development of a distributed-parameter hydrologic model in cooperation with the Survey.[3] This model and others are more fully discussed and evaluated in another paper being given at this symposium.[4] The major objective of the cooperative USGS-BLM modeling program is to develop, test, and verify a hydrologic model that can be used to predict the impacts of surface mining on the hydrology of basins in the coal regions. The model itself will provide:

(1) A means for estimating the hydrologic characteristics and processes of areas where basic hydrologic data are lacking.

(2) The capability of predicting hydrologic impacts from potential coal lease areas.

Program in Support of the Surface Mining Act

The passage of the SMCRA resulted in the Survey undertaking a supporting hydrology program; the Water Resources Division began immediately to appraise the adequacy of the existing hydrologic data and data networks in all coal areas. Deficiencies in hydrologic data needs were most evident in the Eastern and Interior Coal Provinces because of the emphasis in previous years on Federal coal lands in the Western States. Furthermore, the greater number of mines in the East imposes a much greater permitting load on regulatory authorities, as well as resulting in a greater demand for hydrologic information. The initial efforts have concentrated on the collection of surface water quantity and quality data. The complexity of ground water in the Appalachian coal province makes questionable viable regional studies of the shallower aquifers most commonly impacted by mining. Furthermore, it is expected that site-specific ground-water data will become available via monitoring requirements imposed on permittees.

The program that has been implemented to remedy these deficiencies has several facets. First, additional water quality and sediment data collection have been initiated at several hundred existing continuous record surface-water stations and a limited number of new stations installed on small drainage area streams. Second, similiar data are being collected at significant hydrologic times at several thousand sites established on small streams draining the coal areas. These synoptic data surveys were considered to be the most viable means of acquiring meaningful hydrologic data within a system constrained by time, money, and manpower. This data, along with the continuous record data, will provide the means of appraising the general area hydrology of the coal areas. The types of hydrologic data and collection frequency for both the continuous record stations and synoptic sites are summarized in Table 1.

Hydrologic Assessment Reports

The Survey is preparing a series of Hydrologic Assessment Reports to meet the need for providing timely information on the hydrology of the general areas of mining, particularly in the densely mined Eastern States. These reports are based on existing data as well as on about 1 year of new data collected as described above. These reports will rely heavily on map presentation of data.

As can be seen in Figure 2, there will be 35 of these Hydrologic Assessment Reports covering the Eastern Coal Province and the eastern part of the Interior Coal Province. The reporting units are major regional hydrologic subbasins and correspond to areas of actual and potential coal mining. About half the reports are planned for publication by early 1981 and will provide information for the most intensively mined areas where the the demand for the information is most pressing. As a rule, many individual mines may exist in any one of these report areas with a corresponding number of general areas being defined as they are considered for permitting.

The first completed Hydrologic Assessment Report is the one for area 23 in Alabama. These reports will typically contain the following types of information on the area being reported.

Table 1. Constituents and Schedules for Coal Hydrology Data Collection Program.

Parameters	Continuous Record Stations	Synoptic Sites
Field 1. Discharge 2. Temperature 3. Conductivity 4. pH 5. Alkalinity/Acidity 6. Dissolved oxygen Laboratory 7. Common Ions 8. Fe (total & dissolved) 9. Mn (total & dissolved)	Every 6 Weeks	Once at Low and Medium Flows; Once at High flow if Obtainable
10. Metals on bottom material As, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Se, and Zn 11. Common dissolved constituents Residue, Na, Ca, Mg, K, SiO_2, Cl, F, SO_4, and P 12. Minor elements (total) Ba, Cd, Cr, Cu, Fe, Pb, Mn, Ag, Zn, CN, As and Se 13. Coal Separation	Annually at Low Flow	Annually at Low Flow
14. Suspended Sediment	For Flood Events	For Flood events at 10% of Sites
15. Micro-invertebrates-field only; presence or absence.	Annually at Low Flow	Annually at Low Flow

1. General features to include:
   - a. Geology
   - b. Land forms
   - c. Surface drainage
   - d. Land use
   - e. Soils
   - f. Precipitation
2. Water use and stream classifications.
3. A description of the hydrologic networks including surface and ground water where such exists.
4. Hydrologic data and information on surface water quantity such as:
   - a. Streamflow characteristics
   - b. Low flow
   - c. Flood flow
   - d. Flow duration
5. Information on surface water quality to include
   - a. Specific conductance
   - b. pH
   - c. Sediment
   - d. Iron
   - e. Manganese
   - f. Sulfate
   - g. Trace elements
   - h. Other as available
6. Information on ground water to include
   - a. Source, recharge, and movement
   - b. Water level fluctuations
   - c. Availability
   - d. Quality
7. Water-data sources and references to other information that may be useful in appraising the hydrology of the area.

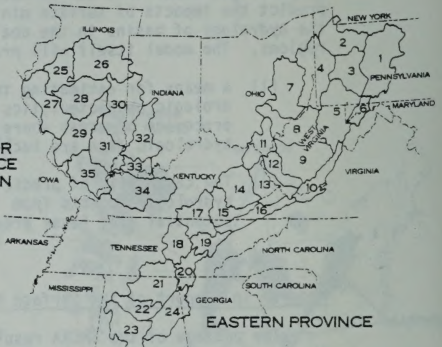

Figure 2. Reporting sub-basins for Hydrologic Assessment Reports in the Eastern Coal Province and Eastern Region of the Interior Coal Province.

Followup reports using the new data being acquired and the improved interpretive techniques being developed are planned.

Probable Cumulative Hydrologic Impacts

One of the requirements in the Act and Regulations subject to considerable intrepretation is how to accomplish meaningful evaluations of the assessment of the cumulative impacts of mining and other land uses. While such concepts are well intended in the effort to see that due weight is given to not overtly impacting the environment, the state-of-the-art to ascertain such assessments is poor. The hydrologist, to accomplish such a task, must have the ability to:

(1) Predict the quantity and quality characteristics of outputs from proposed mining, reclamation, and supporting activities such as haul roads and processing facilities as well as from other land uses; and

(2) Route, and hence predict, the behavior, mode of transport, and eventual quantity of these outputs at the drainage terminus of the general area as defined for one or more mining permit applications

The above would theoretically be required of all of the hydrologic components making up the hydrologic balance. The quantification of the outputs and the determination of the probable hydrologic consequences of the proposed mining and reclamation operation is the responsibility of the permittee. The Federal or State Regulatory Authorities would be responsible for evaluation of cumulative impacts of the mining operation in question considering other mining and land use inputs on the general area. Assuming the cumulative impact assessment could be made, it is not clear as of yet what is an excessive impact. The hydrologic "health" of the general area may possibly be ascertained from the Survey's hydrology program. Complementary to this is the applicants own site-specific hydrologic data. Procedures for determining cumulative impact analysis, and how rigorous the anlaysis must be is yet to be resolved. Considerable research is underway both in the field and laboratory by the Geological Survey and other agencies to better quantify the input factors as well as to predicting their fates. Numerous models are being investigated to determine their potential for use in determining impacts and improving the art of hydrologic predictions for small upland watersheds. It remains to be seen if the data input requirements for such models are reasonable in light of the thousands of mines that must be permitted and the resulting costs of such efforts. Until additional research can be done along these lines, it may be necessary and indeed advisable to use the knowledge and tools available to make good engineering judgments as to cumulative impacts, nothing more. This can, of course, leave both the permittee and regulatory authority open to criticism but the simple fact is that the present state-of-the-art does not permit precise evaluations of cumulative impacts.

References

1. U.S. Congress, "Surface Mining Control and Reclamation Act of 1977," Public Law 95-87, August 3, 1977..

2. Office of Surface Mining, "Surface Coal Mining and Reclamation Operations, Permanent Regulatory Program," Book 3, Vol. 44, No. 50, Federal Register, March 13, 1979.

3. Bureau of Land Management, "Resource and Potential Reclamation Evaluation, Alton Study Site," EMRIA Report No. 4-1975.

4. M. E. Jennings and others, "Field Studies for Verification of Surface Mining Hydrologic Models," Paper at the 1980 Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 1-5, 1980.

5. J. R. Harkins and others, "Hydrologic Assessment, Eastern Coal Province Area 23, Alabama," U.S. Geological Survey Water Resources Investigations 80-683, June 1980.

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References

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5. J. R. Harkins and others, "Hydrologic Assessment, Eastern Coal Province Area 23, Alabama," U.S. Geological Survey Water Resources Investigations 80-683, June 1980.

WESTERN MINED-LAND REHABILITATION RESEARCH WORKSHOP: RESEARCH NEEDS

Developed under the direction of the Research Needs Committee
(members listed in appendix B).

Site disturbances by mining, mineral-waste disposal, and mineral exploration greatly alter soil, water, plant communities, land use, and aesthetics. These alterations often affect a much larger off-site area. Researchers can develop the technology to assure that drastically disturbed land can be rehabilitated to avoid long-term pollution and other environmental problems. Researchers can also develop methods for predicting which sites cannot be reclaimed, and forecast the impacts if sites are disturbed. The land's high value combined with the need for the energy and mineral resources require that researchers strive diligently for a suitable technology level to minimize adverse impacts. The most pressing problem for today's researchers appears to be development of technology for areas with special requirements such as arid, alpine, acid, and sodic sites.

In this report, the identification of research needs and emphasis areas represents the best collective judgment of informed and dedicated specialists concerned with the direction and role of research in mined-land rehabilitation. Concerned agencies and individuals were invited to submit a list of research needs prior to a workshop. A small committee then categorized those research needs. Workshop participants were given an opportunity to critique and add to the list. We are confident that the information provided by the workshop participants will provide valuable input into research programs, and that results will pay off in more effective and efficient rehabilitation of western minelands.

Research needs are categorized as follows: (1) Reclamation Planning, (2) Spoils Placement and Grading, (3) Soil Preparation and Treatment, (4) Spoil-Soil-Plant Interactions, (5) Planting and Plant Materials, (6) Hydrology and Air, (7) Wildlife and Fisheries Habitat, and (8) Postreclamation Management. Technology Transfer is highlighted as another major activity needing improvement if minelands are to be rehabilitated to their potential.

We recognize an across-the-board need to study the economics of reclamation and to consider the socio-economics and other off-site impacts of mining. Many of the identified needs are highly critical in areas where technology gaps currently exist.

SPECIFIC RESEARCH NEEDS

I. Reclamation Planning

To a large degree, the effectiveness and economy of reclamation depends on early integration of reclamation objectives into plans for mineral operations. Reclamation planning that occurs prior to mineral extraction allows greater flexibility in the mining process. Reclamation planning must also reflect the maximum use of the mineral resource.

Policy makers and land managers need more guidance on the various stages of reclamation that are related not only to release of the bond, but also to postbond ecological changes.

Key research needs for better and more cost effective reclamation guides include:

1. Determine alternative land uses.

2. Develop cost:benefit models for alternatives.

3. Develop guidelines for setting reclamation goals and standards on a site-specific basis.

4. Compare impacts of short term stability needs with long-term natural healing.

Other important needs are:

1. Predict both short-term and long-term potentials for revegetation.

2. Predict the impacts of toxic subsurface materials on rehabilitation success.

3. Develop plans that include restoration of critical ecological systems disturbed by minerals activities.

4. Plan reclamation research that will provide information on improving statutory and regulatory processes, and assist in complying with existing requirements.

II. Spoil Placement and Grading

The first phase of reclamation involves grading spoil material and reshaping the land surface to fit into the surrounding landscape. It is also, in many ways, the most important step because it lays the foundation for all subsequent reclamation activities. In addition, a large portion of the expense of reclamation is related to grading and shaping of spoils.

Key research needs include:

1. Develop methods to predict the type and extent of spoil subsidence and how to compensate for it.

2. Develop methods to integrate materials handling and topographic configuration into planned multiple uses following reclamation.

3. Determine how much compaction in the subroot zone is necessary to minimize subsidence and provide for stability of hill slopes. At the same time, determine the level of compaction in the root zone that restricts water and plant root movements into the soil and spoil material.

4. Develop materials handling methods to minimize adverse impacts on surface and subsurface hydrology.

Other important needs include:

1. Analyze potential costs of a given reclamation procedure and compare costs with potential benefits and potential hazards.

2. Develop separation methodology that considers spoil characterization criteria, physical handling methods, and disposal of waste materials.

3. Determine the effectiveness and implications of slope stabilization methods.

4. Develop land forming operations to trap, collect, and conserve water to reduce the need for irrigation in acid areas.

III. Soil Preparation and Treatment

The thickness requirements of suitable plant growth media over spoils differing in physical and chemical characteristics are very important to overall reclamation success. The procedures used in handling topsoil may also greatly influence the reclaimed land's productivity. These procedures include the amount of time the topsoil is stockpiled, how much compaction occurs during spreading, and whether horizons are segregated. The amount of time for stockpiling relates to the soil's ability to serve as a seed and plant stock source.

Key research needs include:

1. Determine plant growth media requirements based on intended land use, potential spoil toxicity, and availability of topsoil.

2. Develop suitable plant growth media substitutes where little or no topsoil is available.

3. Refine salvage, handling, and reapplication procedures such as:

a. Ameliorate adverse interface effects caused by textural differences.

b. Determine feasibility and effects of multiple lift topsoiling and subsoiling.

c. Determine effect of topsoil storage time and configuration on important soil properties.

4. Determine the mechanism and extent of migration of salts and heavy metals in reclaimed land.

5. Determine what amendments are suitable and practical in the reclamation of acidic and sodic soils.

6. Develop practical soil amendment procedures such as the use of organic material to increase microbiological activity.

7. Determine the effects of soil amendments such as organic residues, fiberous materials, various waste materials, and inorganic materials on soil erosion, compaction, water infiltration, structural development, and water holding capacity.

IV. Spoil-Soil-Plant Interactions

Soil is a living ecosystem. Establishment, productivity, and longevity of vegetation is to a large degree a function of soil-plant interactions .

Physical, chemical, and biological characteristics of soils affect plant growth directly, and many soil organisms are synergistic with plants and are key to vegetation development. Other soil organisms as well as some plant species may be antagonistic or pathogenic and have undesirable effects on establishment and development of plant communities. Biogeochemical cycling and nutrient availability are strongly controlled by soil microorganisms, and many scientists believe that low-cost manipulation of soil biology and plant composition could yield high payoffs. Of long-term consequence, cycling of organic matter and nutrients by vegetation and soil organisms is a prime factor in soil development and ecosystem stability.

Some of the key research needs are:

1. Gain understanding of biological factors in soil development, and propose alternatives to more quickly develop a stable and desirable growth medium.

2. Develop technology for stimulation of biological fixation.

3. Determine when and how to use mycorrhizae on mine spoil plantings.

4. Utilize basic and applied studies to determine and match nutritional requirements of plant species with nutrient availability on mine sites.

5. Develop basic physiological data for native plánt species, including soil biological aspects that are concerned with water relations, production processes, and stress responses.

Other research activities that should be expanded for mine sites include:

1. Determine the importance of soil microorganisms in plant rhizospheres.

2. Study soil biological processes as related to maintaining a healthy soil ecosystem during topsoil movement and storage.

3. Determine the importance of toxic material uptake by plants, including the fate and consequences of toxins in community functioning and development.

4. Determine the role of plant-soil interactions in overcoming soil compaction problems on mine soils.

V. Planting and Plant Materials

Adequate reclamation of drastically disturbed sites such as strip mines requires suitable methods for establishing an acceptable ground cover. In the past, orthodox range seeding practices and species commonly used in range and pasture seeding have been used. Research should be innovative in developing seeding methods specifically devised for mined-land reclamation and determining or developing species particularly adapted to mined-land reclamation.

Some key research needs are:

1. Develop improved strains, varieties, and seed sources having a broad gene base specifically suitable for reclaiming mined lands. Emphasis should be on improving native species. Although many native species are difficult to establish and have poor seed-production characteristics, experience indicates that both establishment and seed production can be greatly improved through selection and breeding.

2. Determine germination and establishment requirements for native species. The technology for establishing many native species is lacking, but there is a strong demand (particularly from regulatory agencies) that native species be planted.

3. Develop technology to establish a diverse mixture of species and a diversity of habitats. Careful selection of seed mixtures does not assure that the established stand will have a similar species mixture. The problem exists not only for simple mixtures, such as a grass-legume pasture mix, but also for complex mixtures designed to introduce several species needed to produce the desired species diversity.

4. Continue testing for adaptability so that a larger number of adapted species are available. Especially needed are adapted shrubs and forbs, and plants capable of reseeding themselves in their new environment.

Other research activities that need to be expanded on mine sites are:

1. Develop readily available native plant seed sources including technology for seed production and methods to reduce insect and disease damage.

2. Develop methods, particularly for shrubs, to predict and control seed dormancy problems.

3. Obtain knowledge of ecophysiology with emphasis on mechanisms for drought and cold tolerance, and rooting patterns.

4. Develop scientific criteria for determining the vegetation component of "successful" reclamation.

5. Develop equipment for site preparation and seeding of both large and small disturbed areas.

6. Determine how initial site protection (nurse crop) can best create an improved environment for permanent vegetation establishment.

VI. Hydrology and Air

Even though the art and science of mined land reclamation is relatively new, considerable knowledge has accumulated since the early 1970's. However, the hydrological sciences have badly lagged the agronomic and soil sciences, and we are ill-prepared to answer apparently simple questions such as: "In mountainous terrain, how closely should contour terraces be spaced to control erosion of mined lands in a cost effective manner?" or "What changes in plant-available soil-water regimes can be expected as a consequence of mining?" or "How will mining influence streamflow in an arid region?" To promote the efficient use of western water and to protect that resource, as well as other natural resources, we must increase our knowledge about the hydrologic influences of mining.

The following key research needs are broadly worded to give leeway to regional considerations. These represent severe technological gaps in need of additional research or additional development.

1. Develop improved methods for predicting the hydrologic characteristics of mined lands, including the validation of existing methods and models.

2. Determine how the development and the characteristics of groundwater accumulations affect large waste embankments.

3. Develop technology to describe and evaluate the spatial or temporal variability of hydrologic and soil parameters on mined lands.

The following research activities should be expanded.

1. Develop techniques and methods that predict surface water quality impacts of mining on downstream users.

2. Improve existing methods and techniques for predicting gross soil erosion (including sediment yield ratios) by water or wind agents on mined lands. In such erosion models the required number of input parameters should be kept to a minimum.

3. Develop improved technology for water conservation and reuse for industrial process water and water used in reclaiming mined lands in arid and semiarid regions.

4. Determine the changes in the local hydrologic balance due to mining development or to progressive urbanization sometimes associated with mining in arid regions.

The following special research needs were selected because of gaps in technology even though the spatial extent of any one problem is limited.

1. Develop technology for reclaiming alluvial valley floors and restoration of their subirrigation features by capillary fringe action.

2. Develop better and more cost effective dust control techniques on tailings ponds and haul roads.

3. Improve existing technology for increasing plant-available water on arid mined lands, without irrigation.

4. Improve technology for predicting on-site and downstream soil and hydrologic impacts of mining in sulphide mineral ore bodies that generate acid drainage.

5. Develop improved design parameters for sediment ponds especially in maximizing trap efficiency for small and medium size ponds.

6. Develop cost effective guides showing when it is best to leave permanent water impoundments for recreation, agriculture, or wildlife in arid and semiarid regions.

7. Develop techniques for hydrologic and air quality assessment of toxic or hazardous waste disposal.

VII. Wildlife and Fishery Habitats

What will happen to wildlife and fish habitat must be considered in connection with: (1) premining (criteria for permits and licenses), (2) mining (mitigation activities), and (3) postmining (rehabilitation). Many regulations, requirements, standards, and activities are based on partial information about what happens to wild animal populations. There is a need to improve the scientific basis for rehabilitation decisions.

The following basic research areas would fill critical technology gaps:

1. Identify habitat requirements of key species, with emphasis on identification of limiting factors.

2. Improve knowledge of succession of plants and animals on rehabilitated areas.

The following applied research is also needed:

1. Develop ways to provide vegetational diversity to meet wildlife requirements.

2. Analyze alternative topographic conformations to meet wildlife needs. Analyze trade-offs against other objectives, such as erosion control.

3. Evaluate effectiveness of stipulated mitigation practices.

4. Develop methods of propagation, planting, and culture of forbs and shrubs useful for wildlife.

5. Develop special techniques for establishing wetlands, riparian systems, and prairie potholes within rehabilitation areas.

6. Develop wildlife habitat models (conceptual and quantitative) to interract with new basic information, and identify new data and information needs.

7. Develop modifications to rehabilitation criteria to meet wildlife and fishery requirements. (An example: sometimes rehabilitation for agriculture is too intense to provide maximum value for wildlife.)

VIII. Postreclamation Management

Postreclamation management addresses the maintenance of a site prior to bond release and the responsibilities of the land manager following bond release.

Research needed includes gathering and processing information and developing techniques and recommendations for application of the research results.

Specifically, research needs are:

1. Establish reasonable and scientifically based standards and techniques for measuring reclamation success.

2. Develop methods and guidelines to monitor ecosystem dynamics (on a holistic basis) on mined and reclaimed lands. Key ecosystem biotic and abiotic components or variables (ecosystem indicators) for monitoring must be identified to avoid trying to "sample the world."

3. Develop management systems to promote the achievement of proposed postmining land uses and good multiple use management within the constraints of the reclamation plan and postbond release objectives. There is concern over the impact of creating an "oasis" appearance.

TECHNOLOGY TRANSFER NEEDS

For research to be relevant, effective, and economical, there must be good communication between groups such as:

1. Basic researchers
2. Technology applicators
3. Land manager policy makers
4. Industry

This communication is essential to assure that:

1. Research is not duplicated
2. Knowledge gaps are filled
3. Priority of application is appropriate
4. Findings are promptly and properly applied

Currently, there is not a good means of achieving and continuing communication. Some ways of improving communication and transfer of technology are:

1. Identify the probable user at the beginning of the research.

2. Provide "pilot projects" so users have a chance to "see" results.

3. Provide periodic reports of research under way and its status.

4. Recognize and incorporate into technology transfer those research results generated by industry.

5. Recognize that researchers are seldom trained in, nor have time for, effectively transfering results, and that specialists must be used.

Other specific needs are:

1. Package results better.

2. Redesign of CRIS Information system to incorporate surface mining information.

3. Inform regulatory agency administrators of the need to change as better information becomes available.

4. Transfer existing semiquantitative field hydrologic procedures to industry and land managers.

5. Write and distribute review papers.

APPENDIX

Participants - Western Mined-Land Rehabilitation Research Workshop

Western Mined-Land Rehabilitation Research Workshop Agenda

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Western Mined-Land Rehabilitation Research Workshop

Craddock Building/Forest Service Offices
3825 East Mulberry, Fort Collins, CO

10-11 June 1982

Thursday, 10 June

Session Chairman: Bruce P. Van Haveren, Bureau of Land Management

8:00 a.m.	Sign in and pick up materials	
8:15	Welcome - R. Duane Lloyd	
	Announcements - J. S. Krammes	
	Introductions - Bruce Van Haveren	
	Review of Current Research Programs (Highlights of current research, status accomplishments)	
8:45	USDA Forest Service - Intermountain Forest and Range Experiment Station	- R. Duane Lloyd
	USDA Forest Service - Rocky Mountain Forest and Range Experiment Station	- Richard G. Krebill
	USDA - Agricultural Research Service	- John Vetterling
	Bureau of Land Management	- Bruce Van Haveren
	USDA - Soil Conservation Service	- Jack R. Carlson
10:00	Break	
10:30	Department of the Interior, Fish and Wildlife Service	- Phillip Dittberner
	Department of the Interior, Office of Surface Mining	- Bob Schueneman
	Department of Energy, Argonne National Laboratory	- Ralph P. Carter

11:30 a.m.	Lunch	
12:45 p.m.	Environmental Protection Agency	Eugene F. Harris
	Oil Shale Task Force	Willard Chappell
	TOSCO	Joe Merino
	Colorado State University - Range Science	Edward F. Redente
2:00	Break	
2:30	Brigham Young University	Howard C. Stutz
	Western Regional Research Coordinating Committee 21	Gary A. Halvorson, Chairman, North Dakota State Univ. John Thames, Univ. of Arizona Burns Sabey, Colorado State Univ. Walter Gould, New Mexico State University Ed Depuit, Univ. of Wyoming
4:30	Identification of Research Needs	Keith E. Evans, Chairman
5:30	End of day	

Friday, 11 June

8:00 a.m.	Research Needs (Con't)
10:00	Break
12:00 noon	Close Workshop

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